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Improved conceptual models methodology (ICoMM) for validation of non-observable systems

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DISSERTATION

IMPROVED CONCEPTUAL MODELS METHODOLOGY (ICoMM) FOR VALIDATION OF NON-OBSERVABLE SYSTEMS

by

Sang M. Sok

December 2015

Dissertation Supervisor Eugene Paulo

This thesis was performed at the MOVES Institute

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13. ABSTRACT (maximum 200 words)

This dissertation expands the current view of development and validation of conceptual models (CoM) of non-observable systems (NOSs) by using systems engineering (SE) and systems architecture (SA) methods during the model development process (MDP). A MDP is used to ensure that the models are validated and represent the real world as accurately as possible. There are several varieties of MDPs presented in literature, but all share the importance of the CoM. The improved conceptual model methodology (ICoMM) is developed in support of improving the structure of the CoM for both face and traces validation. The utility of ICoMM is demonstrated through the building of functional, physical, and allocated architecture products that improve the structure of the CoM for traces validation. ICoMM also incorporates a value model to ensure subject matter experts' (SMEs') values are documented early in the MDP for face validation. A well-constructed CoM supports model exploration of NOS when operational validation is not feasible. This dissertation uses a humanitarian assistance/disaster relief (HA/DR) scenario to demonstrate ICoMM's ability to ensure documentation of SMEs' values and that the structure of the COM links SMEs' values to the fundamental objective.

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IMPROVED CONCEPTUAL MODELS METHODOLOGY (ICoMM) FOR VALIDATION OF NON-OBSERVABLE SYSTEMS

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ABSTRACT

This dissertation expands the current method of development and validation of conceptual models (CoM) of non-observable systems (NOSs) by using systems engineering (SE) and systems architecture (SA) methods during the model development process (MDP). A MDP is used to ensure that the models are validated and represent the real world as accurately as possible. There are several varieties of MDPs presented in literature, but all share the importance of the CoM. The improved conceptual model methodology (ICoMM) is developed in support of improving the structure of the CoM for both face and traces validation. The utility of ICoMM is demonstrated through the building of functional, physical, and allocated architecture products that improve the structure of the CoM for traces validation. ICoMM also incorporates a value model to ensure subject matter experts' (SMEs') values are documented early in the MDP for face validation. A well-constructed CoM supports model exploration of NOS when operational validation is not feasible. This dissertation uses a humanitarian assistance/disaster relief (HA/DR) scenario to demonstrate ICoMM's ability to ensure documentation of SMEs' values and that the structure of the COM links SMEs' values to the fundamental objective.

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LIST OF ACRONYMS AND ABBREVIATIONS

AQIM	Al Qaeda in Islamic Maghreb
C&C	command and control
COA	course of action
COO	Country of Orange
CoM	conceptual model
COSF	Country of Orange Security Forces
CS	computer science
DES	discrete event simulations
DM	decision maker
DOD	Department of Defense
EFFBD	enhanced functional flow block diagram
ESG	expeditionary strike group
EW10	Expeditionary Warrior 10
FFBD	functional flow block diagram
FLS	forward logistics site
FLSS	forward logistics satellite site
FM	field manual
FP	force protection
GOO	Government of Orange
HA/DR	humanitarian assistance/disaster relief
ICOM	inputs, controls, outputs, and mechanisms
ICoMM	improved conceptual model methodology
IDEF0	Integrated Definitions for Functional Modeling 0
INCOSE	International Council on Systems Engineering
JP	joint publication
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Utility
LHD	Landing Helicopter Deck
LPD	Landing Platform Dock
LSD	Docking Landing Ship

M&S	modeling and simulation
MDP	model development process
MEU	Marine expeditionary unit
MODA	multi-objective decision analysis
MOE	measure of effectiveness
MOP	measure of performance
MORS	Military Operations Research Society
NASA	National Aeronautics and Space Administration
NGO	non-government organization
NOS	non-observable system
OGO	other-government organization
SA	systems architecting
SE	systems engineering
SME	subject matter expert
SOS	system of systems
STS	Space Transportation System
UN	United Nations
USAID	United States Agency for International Development
V&V	verification and validation

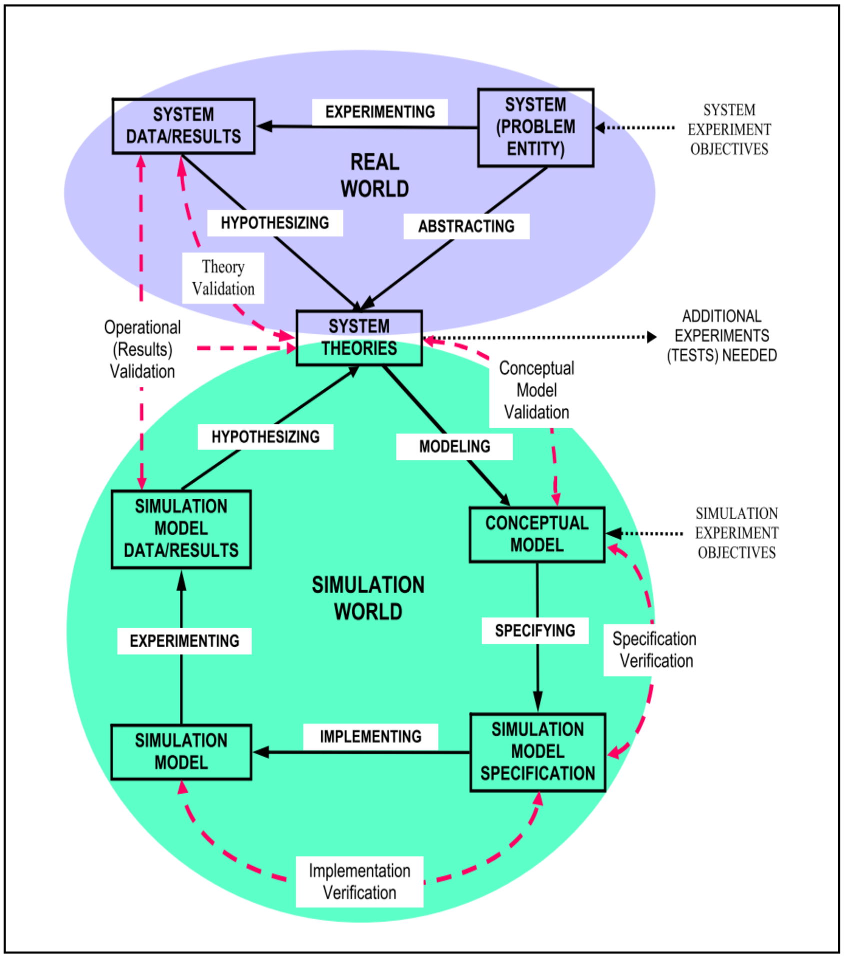
EXECUTIVE SUMMARY

This dissertation focuses on the importance of validation of conceptual models (CoMs) early in the model development process (MDP) by improving the structure of CoMs. A validated CoM early in the MDP also supports the operational validation of a classification of systems known as non-observable systems (NOSs). It presents the use of systems engineering (SE) and systems architecting (SA) methods to improve design and structure of the CoM to help decision makers (DMs) rely on the validation process to gain trust in the model.

Conceptual models are built to provide a visual depiction of an idea of a system that addresses deficiencies in the real world. Several works pertaining to the development of models state the importance of the CoMs. However, literature is lacking on how to build the CoMs that facilitate conceptual validation and support operational validation of NOS.

This research presents an improved conceptual model methodology (ICoMM) that supports the building of validated conceptual models with an improved structure and involvement of SMEs early in the MDP. Figure 1 presents Sargent's evolved MDP. The ICoMM is implemented within Sargent's evolved MDP to improve the structure of the CoM (Sargent 2001, 109). This research uses Sargent's evolved MDP to examine the development of models (Sargent 2001). Sargent's evolved MDP identifies two worlds, real and simulation. The real world is where deficiencies and requirements for systems are identified. The ideas of systems that have the potential to address the deficiencies are identified in "systems theories" (Sargent 2001, 109). Systems theories provide the bridge between the real and simulation worlds. The simulation is where models are built and experiments are conducted. It begins with building of the CoM. The CoM is built based on the systems theories identified in the real world. This dissertation has identified a lack of methodology on building a well-structured CoM.

Figure 1. Sargent's Evolved Model Development Process

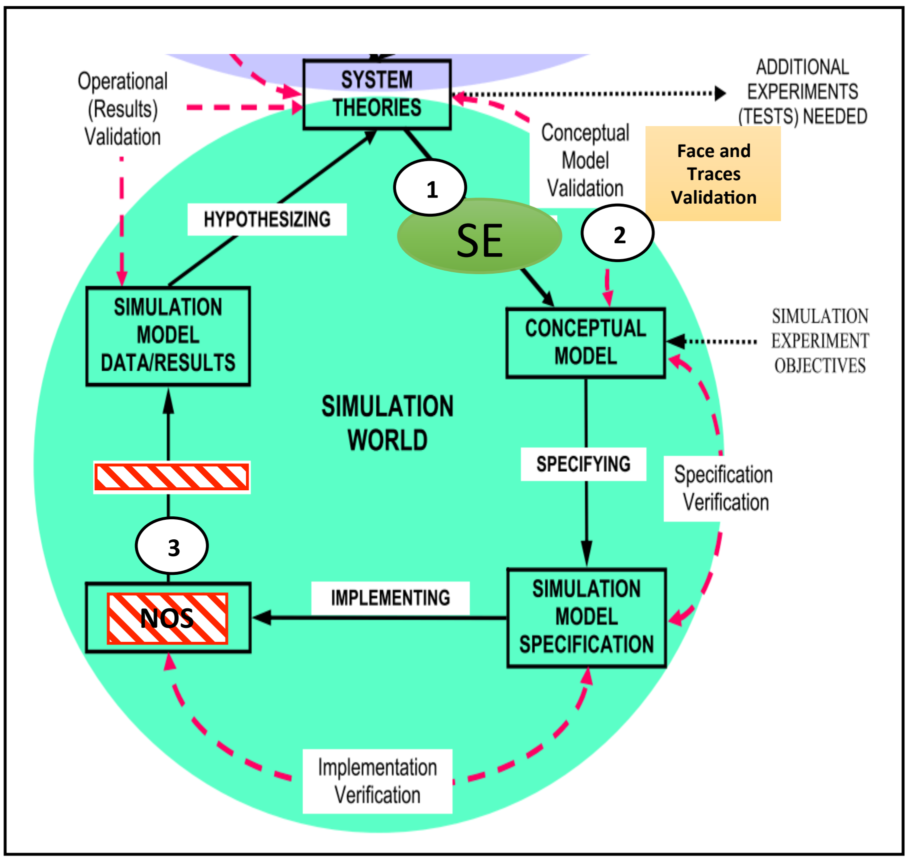


Source: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

ICoMM provides three areas of improvement within Sargent's evolved MDP depicted by white circles with numbers as seen in Figure 2. The first circle is the transition from systems theories to the CoM. Systems engineering and systems architecture processes are applied to design, decomposition, and construction of a CoM based on the operational concept of the system developed in the real world. The improved structure identifies the measurement at the lowest level and links it to a single fundamental objective to facilitate trace validation. The second circle shows the improved structure of the CoM that emphasizes the greater incorporation of documenting SME values to facilitate face validation. The improved structure of the conceptual model

facilitates both top-down and bottom-up passing of information to support traces validation. The third circle is an improved definition of systems that are non-observable within the context of a MDP. This dissertation supplements the definition of NOS to also include future conceptual models, which the interaction between the conceptual system and an external system may not be observable. It demonstrates that a well-structured CoM supports the operational validation of a NOS with the inability to observe system behavior during execution of a simulation through model exploration of the CoM.

Figure 2. Area of contribution

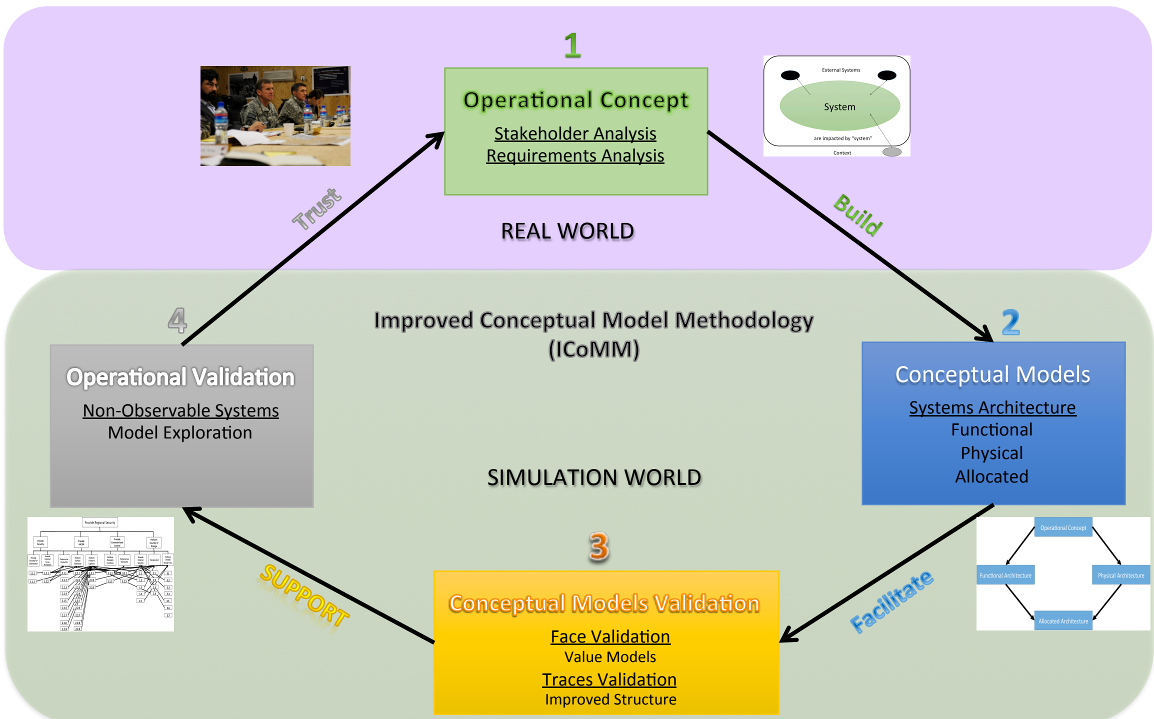


Adapted from: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

The ICoMM is conducted in a sequence of four phases, each defined by activities and products that support the three areas of contribution mentioned earlier. Figure 3 shows the visualization of ICoMM. ICoMM begins by using an operational concept to

create a system to address the identified need of the stakeholders. Next, a CoM is created using SE and SA to visually model the system and its components, as well as its interaction with the external system based on the operational concept. The CoM then goes through two validations processes, face and traces validations. Finally, operational validation of NOS is conducted using model exploration supported by the validated CoM.

Figure 3. Improved Conceptual Model Methodology Visualization



ICoMM was applied to a Department of Defense (DOD) humanitarian assistance/disaster relief (HA/DR) mission scenario. ICoMM was compared to previous research using the same scenario. The result of this research revealed that applying SE and SA methods in model development improved the structure of the CoM. The new structure facilitated the traceability of multiple measurements of functions to a single fundamental objective, as opposed to the multiple objectives identified in previous research. It also identified the functions and components of the external system that affected the fundamental objective. ICoMM also established measures to hold SMEs accountable by documenting their values of the functions to be executed by the system

supporting face validation. Finally, using the ICoMM created a validated CoM prepared to conduct model exploration. This dissertation did not attempt to simulate the HA/DR mission. The scope of this research was to improve system definition and model structure from the previous research.

The intent of ICoMM is to be used in multiple scenarios. It is applied when developing systems that are conceptual in nature to address needs in the real world. ICoMM improved the structure of the CoM to ensure traceability to a single fundamental objective and SMEs participation early in the MDP. If applied correctly, analysts can present DMs a well-structured model they can trust to make decisions that impact the entire organization.

REFERENCE

Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 106–114.

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I. INTRODUCTION

The use of modeling and simulation (M&S) is an important aspect of the development of systems. An important aspect of M&S is the validation of the models to ensure that the models accurately represent the system in the real world. Validated models ensure that decision makers (DMs) are able to trust the results of the model to make decisions. This dissertation addresses the need for improvement of the validation methods of conceptual models (CoMs) to support operational validation of non-observable systems (NOSs). It presents the use of systems engineering (SE) and systems architecting (SA) methods to improve design and structure of the conceptual model that, in turn, will help DMs rely on the validation process to gain trust in the model.

A system, defined by the International Council of Systems Engineering (INCOSE), is "a construct or collection of different elements that together produce results not obtained by the elements alone" (INCOSE 2015). Some systems are so large and complex that models of the system must be made to achieve better understanding of how the actual system will perform in the real world (Parnell, Driscoll, and Henderson 2011). Models are abstract representations of an actual system and are built before a system is fully produced or executed in the real world. Models are used to better understand aspects of the system that may not be identified in the real world (Sokolowksi and Banks 2009, 5).

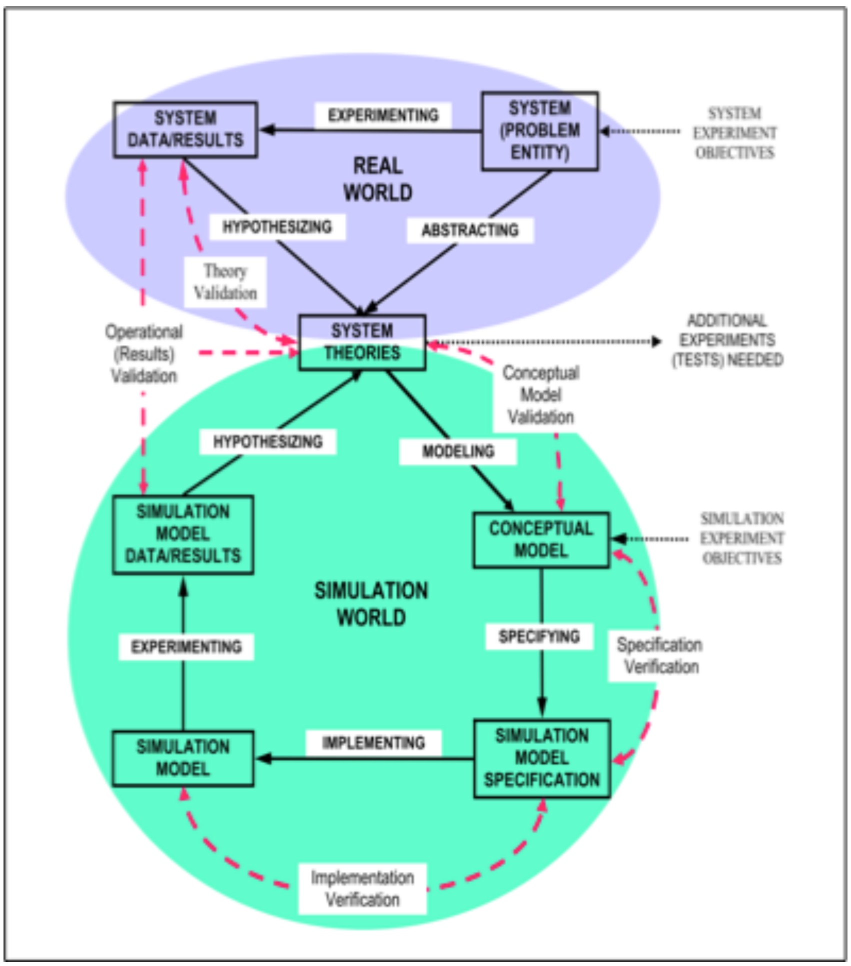
Several model development processes (MDPs) are presented in the literature as guides to building models that represent systems. The evolved MDP of Sargent (2001) is the primary example used in this dissertation. In his earlier work, Sargent (1984) introduces several concepts used for this research, such as CoM validation and NOSs, which are discussed in detail in Chapter II.

As the models of systems go through the MDP, the models must be conceptually and operationally validated to ensure the model adequately reflects the user's needs and gains the trust of DMs. The Department of Defense (DOD) (2008) defines validation as "the process of determining the degree to which a model, simulation, or federation of

model and simulations (M&S) and their associated data are accurate representation of the real world form the perspective of the intended use(s)" (3).

Figure 1 displays the evolved Sargent's MPD presented in 2010. The first phase of Sargent's evolved MDP is to build the CoM. The CoM is a description of how the functions of the system will be executed to achieve the fundamental objectives defined by the DMs (Law 2007, 255). A detailed structured CoM provides traceability from performance measurements to the achievement of the fundamental objective. The traceability supports the validation of the CoM.

Figure 1. Evolved Sargent's Model Development Process



Source: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

Sargent (1984) presents two methods of CoM validation, face and traces validation techniques. Face validation, as Sargent describes it, involves subject matter experts (SMEs) with knowledge of the system, stating whether the design of the conceptual model is accurate and the input-output of the model is reasonable. Also known as a "peer assessment," it is a subjective, yet effective method to evaluate models (Balci 1986). The other CoM validation method is traces validation. Traces validation follows the logic of the model to determine if the model is accurate and meets the need of the user (Sargent 1984). A validated CoM supported by the two validation methods contributes to the operational validation of the model performed later in the MDP.

Operational validation of the model is to determine if the model's output meets the intended purpose of the model. An important factor that affects the operational validation is whether the system is observable or non-observable (Sargent 1984). It is possible to collect data on the operational behavior for observable systems, while it is not possible for NOSs. Sargent (1984) uses two types of approaches for operational validation, subjective and objective, for both types of systems. There are two subjective approaches for operational validation of NOSs, exploration of model behavior and comparison to other models. The objective approach described by Sargent uses comparison to other models using statistical tests (Sargent 1984). An example of NOSs is future conceptual systems that are not in existence. The only operational validation method that can be used for future conceptual systems is the subjective approach of exploring model behavior (Sargent 2013). Future CoMs are systems that are not in existence and have no other systems or models of system to compare. Operational validation of the models of future conceptual systems is unfeasible if it is used in "what-if" environments or is used to forecast system results (Balci 1986). The model output behavior(s) must be thoroughly explored to improve the confidence in the model of a NOS (Sargent 2013).

This dissertation presents the idea that deviations from the intended outputs identified as a result of the simulation of a model of a NOS must be referred back to the CoM for model exploration. The structure of the CoM is reexamined to identify functions or objectives that may contribute to the deviation of the intended output. Based on the

updated information, DMs are able to make decisions quickly to adjust their course of action, identify new objectives, or give greater weight to different functions. It is assumed that if the simulation results of models of NOSs were as intended, the validated CoM would support operational validation and no further action would be needed.

A. BACKGROUND

Throughout history, people have used models to represent ideas, buildings, weapons, and even armies. Sokolowski and Banks (2009) use the game of chess, developed in the 15th century, to provide an example of M&S in history. The fundamental objective in chess is to obtain "checkmate," by capturing the king.

The chess pieces represent the components of the system, the chessboard is the simulated battlefield, and the execution of the game is the simulation (Sokolowski and Banks 2009). The game of chess can be seen as the origin of the modern-day war game. A set of rules outlines the functions of the pieces. The user determines the strategy used to execute the functions. Chess is a classic example of how DMs have used M&S to understand the system and the functions of components to achieve a fundamental objective.

As time progressed, systems have become more complex. Modern buildings are taller, weapons are more lethal, and armies are bigger with capabilities beyond what was imagined when chess was developed in the 15th century. However, models are still used by engineers, scientists, and analysts to help gain better understanding of these complex systems. Models have also become complex to represent complex systems.

Models are used to represent ideas either to improve an existing system or to introduce an entire new system to provide for a new need. These types of models are known as CoMs that are "theoretical representation of systems based on anecdotal or scientific observations" (Parnell, Driscoll, and Henderson 2011, 104). CoM development is the first task identified in several MDPs. The CoM provides the initial understanding of the purpose, assumptions, components, relationships, and interactions of the system. Diagrams and flow charts are used to create CoM. These drawings include a purpose, input variables, output variables, and controls of the CoM. The Integration Definition for

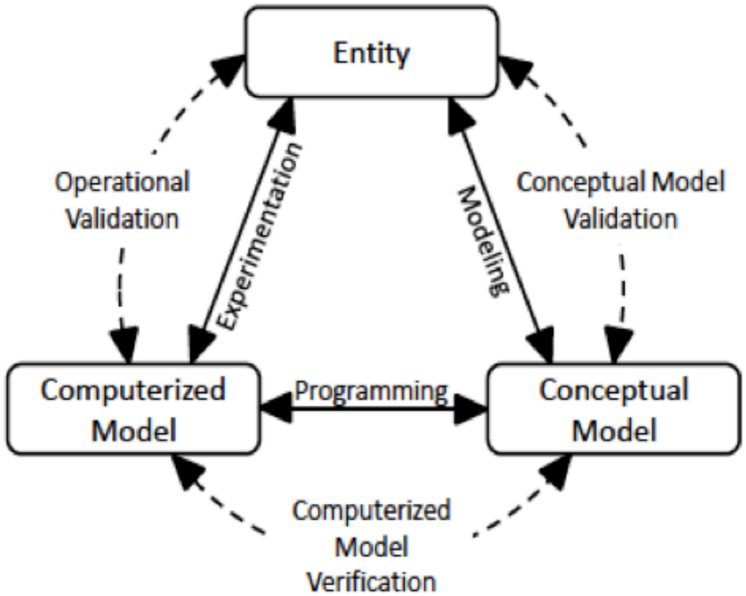
Function Modeling (IDEF0) language used in SE is a tool, which formally describes the system. The IDEF0 is used by this dissertation and is further discussed in Chapter II.

It is important that the DMs trust the CoM accurately represents the system to accept and use the model. The CoM must be validated to gain the confidence and trust in the model. Sargent defines CoM validation as "determining that the theories and assumptions underlying the conceptual model are consistent with those in the system theories and that the model representation of the system is 'reasonable' for the intended purpose of the simulation model" (Sargent 1984, 118).

B. PREVIOUS RESEARCH

Many articles have been published pertaining to the concept of CoMs and the validation of models. However, most refer to the definitions of CoMs and their validation presented by Robert Sargent. In 1979, Sargent wrote one of the earliest publications in the area of validation and presented a simplified model development process. The simplified process had three nodes that represented the system: problem entity, conceptual model, and computerized model. Between each of the nodes is either a validation or verification that was conducted to ensure the model in each node accurately represented the system as it progressed through the MDP. Sargent identified the CoM also as a "flowchart," which led to the assumption that a flow chart was the primary method to represent the CoM. Sargent also presented various validation techniques to include face and traces validation. Sargent subsequently published articles on verification and validation (V&V) of models, introducing new concepts every few years.

Figure 2. Initial Version of Sargent's Model Development Process



Source: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 108.

In Sargent's (1984) proceedings of the winter simulation conference, Sargent introduced the idea of CoM validation and the techniques used for validation. The CoM validation determines whether appropriate structure, logic, and relationships are identified. In this article, Sargent specifically identifies face and traces validation techniques to be used to validate CoMs. He also states that operational validation is affected by whether or not the operational behavior of the system is observable. A system is classified as observable if it is possible to collect data on the operational behavior (Sargent 1984). Sargent uses two types of approaches for operational validation, subjective and objective, for both types of systems. There are two subjective approaches for operational validation of NOSs, exploration of model behavior and comparison to other models. The objective approach only uses comparison to other models using statistical tests. Sargent does not discuss observable systems and NOSs in this article.

In 1986, in Balci's proceedings of the Winter Simulation Conference, Balci introduced a MDP similar to Sargent's MDP. Balci's MDP had several additional steps compared to Sargent's. However, the idea of developing the CoM and validating the overall model remains the same as Sargent's model. The idea of using SMEs for model validation was also reinforced by Balci. He stated that peer assessment is an effective method for evaluating the acceptability of the model results (Balci 1986). Peer assessment consists of a panel of experts who evaluates the system based on their knowledge of the system. Balci (1986) also introduced the idea that SMEs identify indicators, an indirect measure of concepts: "The indicators are weighted and measured with an overall score" (40). However, validation may be unfeasible if the model is applied as a forecasting model to answer the "what if" questions of a system model (Balci 1986).

In 2001, Sargent improved the MDP, first presented in 1984. His evolved MDP is divided into two worlds, the real and simulation. The real world is where the system resides and the models of the system are in the simulation world. Sargent increases the number of phases to five in the simulation world in the evolved MDP from the previous three phases. The evolved MDP has the system theories reside in both the real and the simulation world to serve as a conduit between the two worlds. The four remaining phases in the simulation world are the CoM, simulation model specification, simulation model, and the simulation model data/results (Sargent 2001). The CoM is the logical representation of the system. The simulation model specification is the detailed software program written to implement the CoM in the simulation. The program must be verified to ensure the programming code is appropriate for the particular computer used for simulation. The simulation is the execution of the CoM in the computer. Finally, the simulation model data and results are the outputs of the simulation (Sargent 2001). Sargent adds that high degree of confidence is difficult to obtain for NOSs. Thus, he finds that model exploration of the behavior output should be explored and compared to other validated models if possible.

In 2014, Andrew Turner conducted research on developing models for the simulation of NOSs. Turner's research is the first attempt to develop a method to model NOSs. Turner uses Balci's 1986 MDP to support his methodology. However, Turner

(2014) identifies the primary shortcomings of his methodology as linking the steps of the MDP and correctly identifying the structure of the system impacts on decomposition. Turner (2014), in his future works section, states that “continued research would investigate a process to enable a better transition from system definition to impact variable decomposition” (330). The structure presented by Turner does not link the measurements from the lowest levels in his structure and does not lead to a single fundamental objective.

C. GAP

Research into improving CoMs provides insights into the challenges faced by analysts to create models for simulation that can be trusted by DMs, especially if the systems are non-observable. The research gap identified by this dissertation is the lack of a method to build well-structured CoMs. This dissertation presents the idea that a well-structured conceptual model supports both conceptual and operational validations. Currently, there is a lack of research into the design of the CoM to support validation with SME involvement and a logical structure. A validated CoM also supports operational validation of NOS. An operational validation is unfeasible when the behavior of a model of a system is non-observable during the execution of a simulation. The only way to make sense of the simulation results is to conduct model exploration (Sargent 2007). There are no current methods of exploring models of NOS. The CoM is the only model available for model exploration of NOS. This dissertation emphasizes the idea that an improved structure of the CoM provides increased traceability and greater accountability of SMEs.

Turner’s work on modeling of NOSs for simulations is significant because it is unique. All other references to NOSs in the body of literature have been to define the term and the concepts. It does not demonstrate how to build the models or validate them for system use in the real world. Turner uses the limited information within the body of knowledge to present a method of modeling NOSs.

Finally, Turner identifies two areas of continued work in the field of modeling of NOSs for simulation at the end of his research. It is in these areas where further contributions to the body of knowledge are made:

- Better transition from system definition to impact variable decomposition.
- Proper development of structure for decomposition (Turner 2014, 330).

Again, SE methods are used in this research to continue the previous work to improve the method of validation of models of NOSs so they are traceable and support current SME validation methods.

Current research does not present methods to document SMEs values for face validation. Sargent notes that faces validation involves SMEs, but does not present how to involve SMEs in the development of models. There is also a lack of literature of how to conduct model exploration should the output of the simulation deviate from the intended output.

The following research questions arise as a result of these identified gaps:

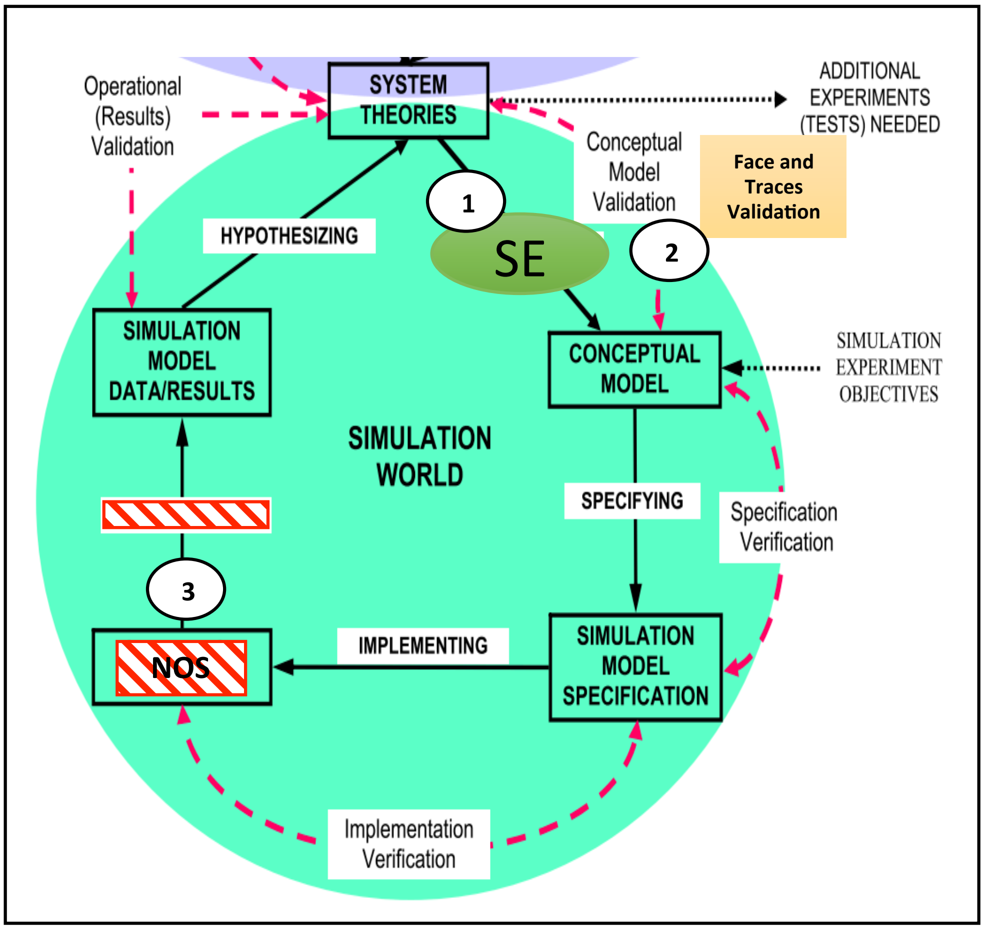
- Is there a formal method of building a CoM of a system? If not, what are the methods available to build a CoM system?
- What improvements can be made to the structure of the CoM to improve traceability of the model for validation?
- How can SMEs values be documented to support CoM development and accountability during face validation?
- Does model exploration of the CoM of a NOS support operational validation?
- Can improving the CoM by using SE and SA methods support conceptual and operational validation when applied to a study of DOD organizational system during a humanitarian assistance/disaster relief operation (HA/DR)?

D. CONTRIBUTION

The primary contribution of this dissertation is the M&S domain. Figure 3 shows the areas of contribution as noted by the three white circles and the corresponding numbers. This dissertation presents a methodology that improves of the structure of the CoM for validation from previous research. The first circle is the transition from systems theories to the CoM. Systems engineering and systems architecture processes are applied to design, decompose, and construct a CoM based on the operational concept of the system developed in the real world. The improved structure identifies the measurement at the lowest level and

links them to a single fundamental objective to facilitate trace validation. The second circle shows the improved structure of the CoM that emphasizes the greater incorporation of documenting SME values to facilitate face validation. The improved structure of the conceptual model facilitates both top-down and bottom-up passing of information to support traces validation. The third circle is an improved definition of systems that are non-observable within the context of a MDP. It adds to the definition that, for future conceptual models, the interaction between the conceptual system and an external system may not be observable. This dissertation demonstrates that a well-structured CoM supports the operational validation of a NOS with the inability to observe system behavior during simulation execution through model exploration of the CoM.

Figure 3. Areas of Contribution



Adopted from: Sargent, Robert. 2001. “Some Approaches and Paradigms for Verifying and Validating Simulations Models.” *Proceedings of the 2001 Winter Simulation Conference*, 109.

E. RESEARCH APPROACH

This dissertation presents a methodology to present DMs with a visual CoM. The idea of building a CoM is taken a step further by establishing a methodology based on SE and SA concepts and assert that the methodology improves CoM validation. This research acknowledges that the methodology presents only a small improvement on the foundation of the idea of CoMs and its validation. However, it does address specific areas of improvement identified by previous research, systems definition, and structure. Future works section points to the areas that should be examined as further research in this area.

The result of the research is the formalization of an Improved Conceptual Model Methodology (ICoMM). ICoMM was used to build a CoM of the HA/DR mission used by a previous research to demonstrate the improved method of defining the system and structure of the model.

F. DISSERTATION ORGANIZATION

Chapter II reviews model development processes and validation methods. System engineering and systems architecture are also reviewed. It covers systems design and architecting techniques to decompose a system to understand its requirements, the functions and the components, and how it interacts with an external system. The definition of NOS is explored to gain an understanding of the challenges of modeling NOS and its operational validation.

Chapter III presents the improved conceptual model methodology (ICoMM). ICoMM uses SE and SA processes to improve the structure of the CoM that facilitates validation.

Chapter IV demonstrates the utility of this research by exploring the conceptual modeling of NOSs. A humanitarian assistance/disaster relief (HA/DR) scenario used in previous research is explored in this research to improve the design of the interaction between the system and the external system. SE and architecting principles are applied to show improved traceability from the measurements of performance and effectiveness to the fundamental objective.

Chapter V concludes the dissertation with a summary of the research and contributions. Recommendations for extensions of this research are included in the future works section.

II. LITERATURE REVIEW

The focus of this dissertation is improving the CoM by establishing a structure that supports face and traces validation of the CoM. It also investigates the operational validation of NOSs. This dissertation presents the integration of SE and SA methods to improve the structure of COMs. Face validation is also enhanced by inclusion of SMEs' values early in the MDP.

It is important to establish a baseline of understanding of models and how models help to gain insights of systems. First, this chapter reviews the definition of models and its uses. Next, a review of several MDPs is presented with an emphasis on Sargent's (2001) evolved MDP. Sargent's evolved method for model development is the foundation of this dissertation. According to Sargent (1984), there are two main model validation phases of the MDP, the CoM validation, and the operational validation. SE and SA methodologies are review to understand how a system is decomposed to identify its functions and components. The decomposition of the systems helps to improve the structure of the CoM and its validation. Operational validation is conducted based on the results of a simulation (Sargent 2010). For NOS, operational validation is difficult due to its complexity.

Many categories of systems already exist in the SE domain. Blanchard and Fabrycky (2006) describe a few of the classifications of systems, such as natural and human-made, physical and conceptual, static and dynamic, closed and open systems. This chapter reviews the classification of systems known as observable systems and NOSs to identify the differences and how both are operationally validated. The term NOS is a difficult concept to understand and not used very often in the M&S domain.

Very little is written on the subject of NOSs within the M&S domain. To gain an understanding of modeling NOS, it is important to establish a foundation of understanding of the definition, engineering, design, and architecture of systems. Parnell, Driscoll, and Henderson (2011) acknowledge that analysts must consider the interdisciplinary systems thinking approach to model systems. The MDP and the

validation techniques are discussed to present SE integration into a MDP. This chapter also establishes how a validated COM supports the operational validation of NOS.

A. MODELS

Models are important tools in today's society. People depend on models in everyday life, from the engineer who tries to improve the structure of an airplane to architect who strives to build a more efficient home. In similar ways, models help DMs gain information about systems to make decisions. Thus, a model is defined as "an abstract representation of a system" (Parnell, Driscoll, and Henderson 2011, 99).

1. Model Development Processes

It is imperative that all models go through a MDP. A MDP can be as informal as a simple drawing on a napkin or as formal as a methodology presented in an engineering class. In 1979, Robert Sargent presented his simplified version of the MDP during the Winter Simulation Conference. Since then, many others have presented different MDPs. However, Sargent's MDP has been the main source cited by many in the model development community and THER DOD. There have been several updates to Sargent's 1979 MDP; however, the basic concepts of model development remain relevant.

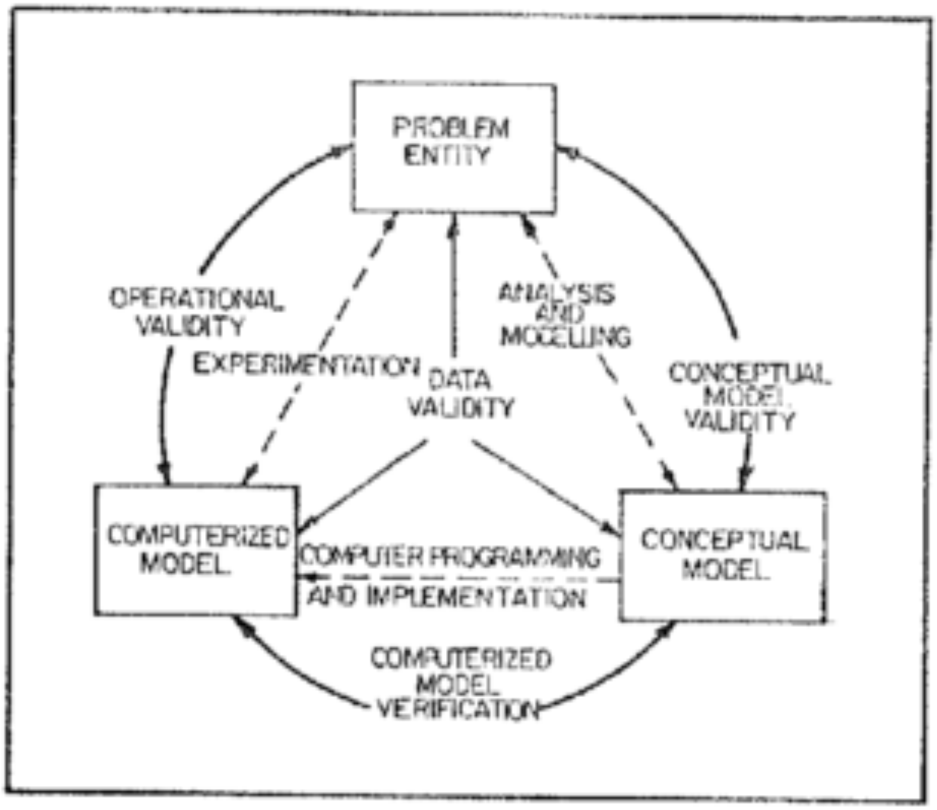
a. Early Sargent's Model Development Processes

Sargent used his simplified modeling process model to explain the verification and validation steps necessary during the modeling process. This dissertation refers to this process as the "Sargent circle," as it was used in Turner's (2014) dissertation.

The circle in Figure 4 has three main components: the problem entity, the conceptual model, and the computerized model. The first component is the problem entity. Sargent (2007) calls this component the "system" in future updates of his paper. He describes the system as "real, proposed, idea, situation, policy, or phenomena to be modeled" (Sargent 2007, 126). The next component of the circle is the development of the conceptual model. It is the model developed based on the inputs from the stakeholders of their understanding of the system. The final component of the circle is the computerized model. The computerized model is programmed based on the CoM to run a

simulation on a computer (Sargent 1984). There are V&V aspects between each of the components. V&V is discussed in further detail later in the chapter.

Figure 4. The Original Sargent Circle



Source: Sargent, Robert. 1984. “A Tutorial on Verification and Validation of Simulations Models.” *Proceedings of the 1984 Winter Simulation Conference*, 116.

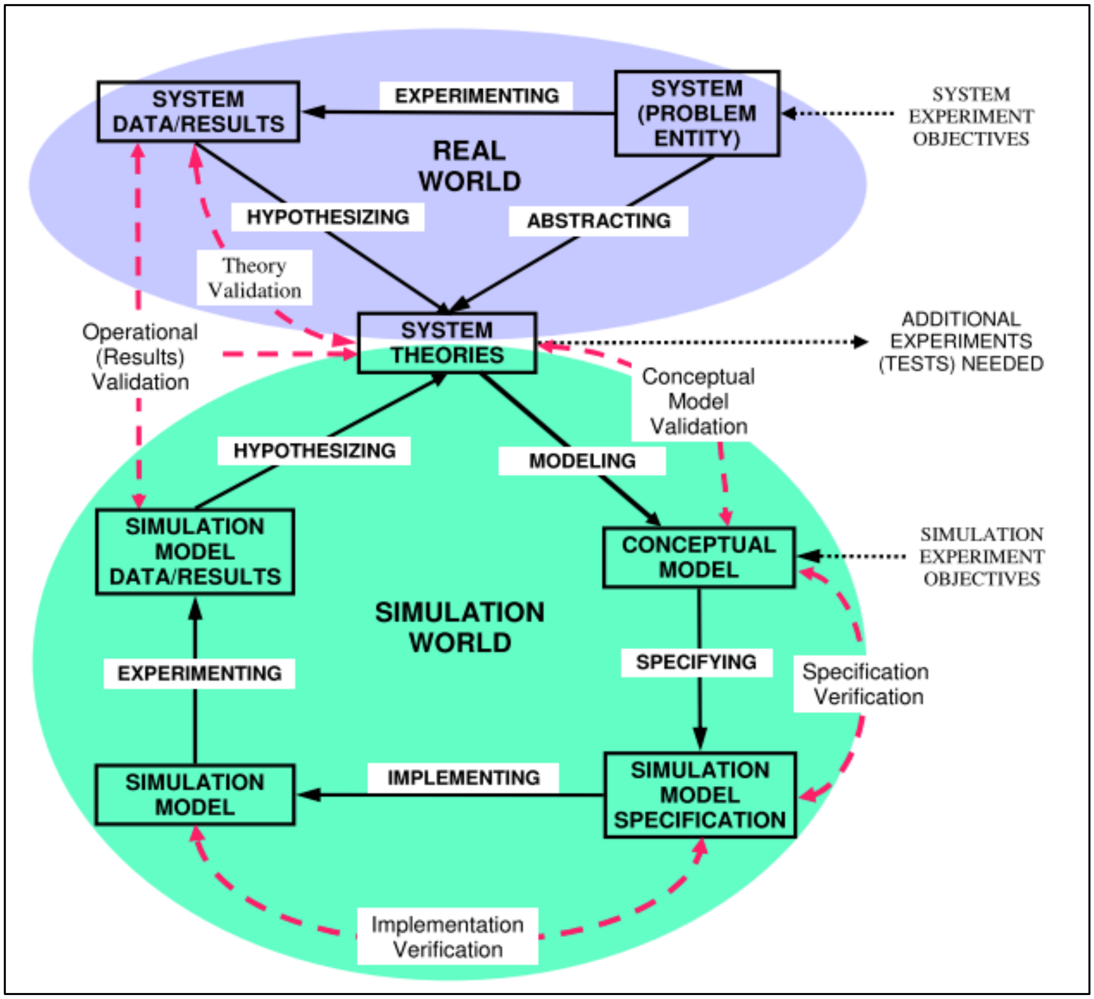
b. Evolved Sargent’s Model Development Processes

Sargent (2001) updated his simplified modeling process and presented it to the American Society of Mechanical Engineers. The updated model is referred as the “Evolved Sargent’s Circle” (Turner 2014, 32). The term “Evolved Sargent’s MDP” is used in this dissertation to demonstrate the application of the Evolved Sargent’s Circle as a MDP. Figure 5 is an example of the Evolved Sargent MDP presented during the 2001 Winter Simulation Conference. The updated model depicts two worlds, the real world

and the simulation world. The real world shows a system subjected to experimentation. The analysts have hypothesized and abstracted ideas of the system based on system the system need and expected results to address the need. The design process of creating the functional, physical and allocated architecture decomposes the system based the system theories from the real world. These ideas are then turned into theories regarding the performance and the expected effects the system will produce. The system enters the simulation world with the established theories to begin construction of the COM. The completed COM is then validated to ensure it reasonably matches the systems theories (Sargent 2010).

The next component of the evolved MDP is the simulation model specification. The products of the CoM are the objectives for the simulation (Sargent 2010). This is the description of the software design and where the specification of the simulation model is verified. The simulation is executed once the specifications have been verified. The simulation is the execution of the CoM developed earlier based on system theories. The results of the simulation are the basis for validation of the model of the system. The evolved circle is much more detailed but the general ideas are the same.

Figure 5. Real World and Simulation World Relationship with Verification and Validation



Source: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

2. Conceptual Models

Sargent states that a CoM is "the mathematical/logical/verbal representation of the problem entity (system)" (Sargent 2010, 169). The CoM is the first model to be built in a MDP. It is built early in the MDP to identify and correct any deficiencies before using more resources throughout the development process. This research has not found a structured methodology on building a CoM. There also is a lack of understanding of how

to achieve a "good" CoM. Teeuw and van den Berg (1997) presented general criteria for development of CoMs quoted here:

- Completeness: The concepts must be expressive enough to capture all "essential aspects" of the real world.
- Inherence (propriety): The concepts should be straight to the point and focus on essential aspects only.
- Clarity: A designer must be able to comprehend the concepts and rules, as well as be able to apply them in models without spending too much time and effort (subjective)

B. VERIFICATION AND VALIDATION

1. Verification

As discussed previously, models are a representation of the system. To ensure that the models are credible representation of the system, they must be verified and validated. A credible model will assist in answering whether the results of the models are accurate depictions of the system. A validated model is also important because the information gained from the model is used by DMs to make decisions. DMs must have the confidence that the results of the model are correct to make decisions that affects the entire organization.

The DOD Standard Practice Document MIL-STD-3022 (2008) defines verification as, "The process of determining that a model, simulation, or federation of models and simulations implementations and their associated data accurately represents the developer's conceptual description and specifications" (10). In the computer science (CS) domain, it "is ensuring that the computer program of the computerized model and its implementation is correct" (Sargent 2010, 166). Verification of the model is generally understood, as the focus was on ensuring that the model was built correctly. The CS interpretation is used to ensure that there are no bugs in the program and each line of code executes as intended. Verification is an important way to ensure that each of the system components performed as expected during the tracing of effects to the objectives of the NOS.

2. Validation

Non-observable systems present unique challenges to the validation process. The MIL-STD-3022 defines validation as

> the process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world from the perspective of the intended use(s) (Department of Defense 2008, 2).

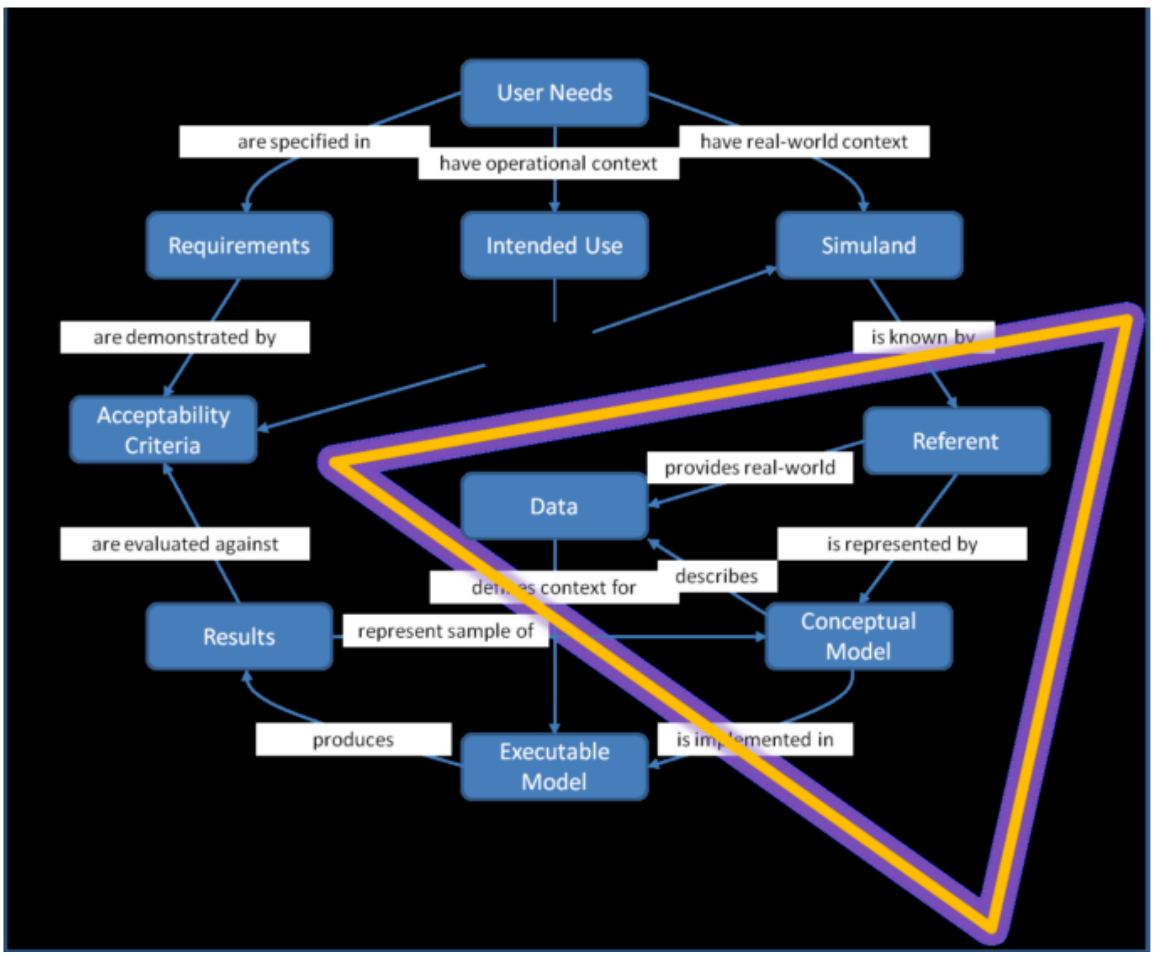
Validation answers the question of the accuracy of the model (Sokolowski and Banks 2009). Numerous validation techniques are well documented in literature. Over 77 V&V techniques can be applied for two major stages in the modeling process (Balci 1986). Sargent (2013) lists 15 validation techniques in his most recent paper. Sokolowski and Banks (2009) list 11 in their modeling and simulation books. All those validation techniques can be grouped into two major types of validation: subjective and objective. Objective validation is the use of mathematics or statistics to validate the model. Subjective validation is relying on non-numerical methods to validate the model, such as face and trace validation techniques. Many times, a combination of objective and subjective validation techniques are used.

Sargent (2010) states that a model is considered valid if the model's accuracy is within an acceptable range established by the stakeholders. The model's accuracy is measured by its results; thus, it is important to identify the variables early in the development process. As we revisit the Evolved Sargent Circle, validation occurs early on with CoM validation and ends with operational validation.

CoM validation is the demonstration that the conceptual ideas that are the bases for the CoM are accurate representations of the real world theories of the system and the models representing the system "are reasonable for the purpose of the model" (Sargent 2010, 173). Many times the face validation technique is an appropriate choice for CoM validation. Face validation is using SMEs or individuals who have knowledge about the system to address whether the model adequately represents the system in the real world. The SMEs normally require the use of flowcharts or graphical models (Sargent 1986), or a set of model equations. This technique is known as traces. Traces validation is tracking the system through each of the components to the overall model to determine if the model is correct.

Appleget, Blais, and Jaye (2013) present the importance of the development of the COM to "provide the developer's interpretation of what is needed to achieve the user's objectives" (Appleget, Blais and Jaye 2013, 5). They state that three essential items are needed for a model to be validated: the CoM, a referent, and the description of the data. The CoM is previously defined. The referent is the laws or science theories that will be used to model the system. The description of the data is needed to ensure that the model has the required collection of data. These three items are known as the "validation triangle" and are part of another model development process. Figure 6 depicts how the validation triangle fits into the overall model development process.

Figure 6. Validation Triangle



Source: Appleget, Jeffrey, and Blais, Curtis, and Jaye, Michael. 2013. "Best Practices for US Department of Defense Model Validation: Lessons Learned from Irregular Warfare Models." *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 3.

An operational validation is conducted to determine if the results of the model sufficiently represent the results of the actual system and its applications. If the model is determined not to represent the system sufficiently, analysts must be able to retrace the model's behavior to identify what caused the deviation. Analysts can use analytical methods to identify the cause to find the deviation and objectively validate the model. If analytical methods are not possible, subjective methods can be used to validate the model.

C. SYSTEM

A system is understood as an integrated set of elements that accomplish defined common objectives (Parnell, Driscoll, and Henderson 2011). A system can consist of a wide-ranging set of elements, such as people, organization, facilities, procedures, collection of hardware and software (Buede 2009). Parnell, Driscoll and Henderson (2011) outline key attributes of a system as the following quoted here:

- Have interconnected and interacting elements that perform systems functions to meet the needs of consumers for products and services.
- Have objectives achieved by system functions.
- Interact with their environment; thereby, creating effects on stakeholders.
- Require systems thinking that uses SE throughout process.
- Use technology developed by engineers from all engineering disciplines.
- Have a systems life cycle containing elements of risk that are (a) identified and assessed by systems engineers, and (b) managed throughout this life cycle by engineering managers.
- Require systems decisions, analysis by systems engineers, and decisions made by managers (3).

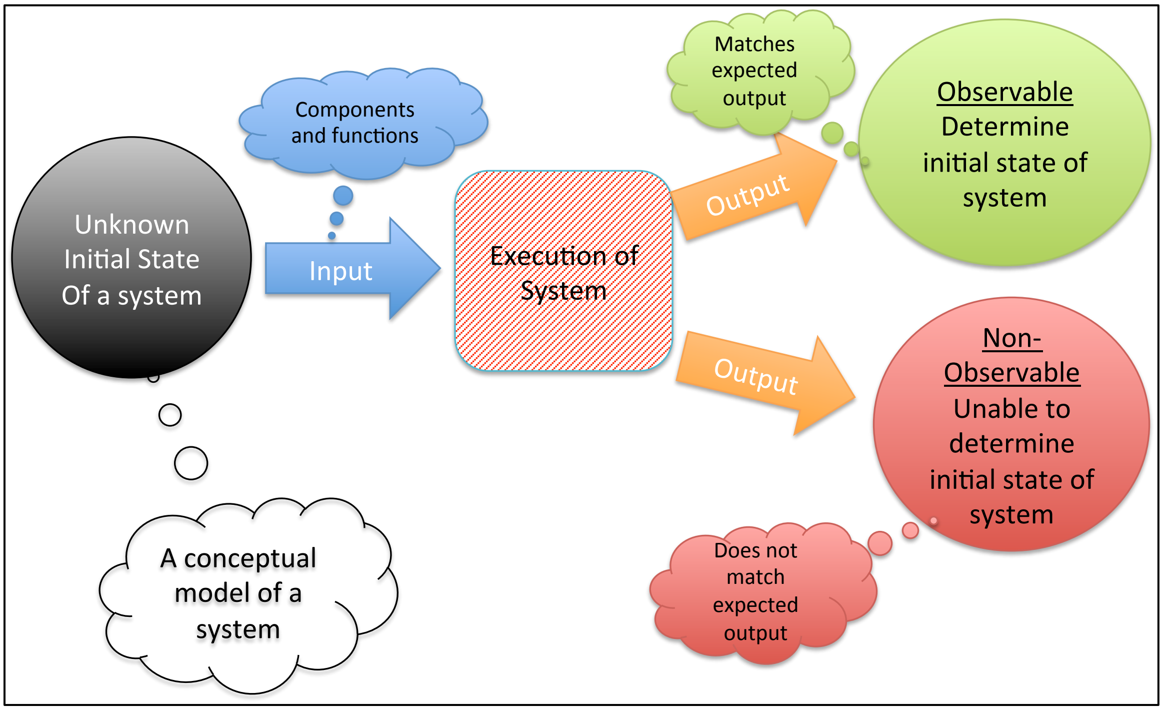
It is important to understand that the elements of an organization are interconnected and interact with each other to support the organizational system. The organization provides services to achieve defined objectives executed by its functions. By providing services, the organization must interact with the environment. This interaction creates effects that the stakeholders must understand to make future decisions about the organization and its processes. Thus, analysts use the systems thinking approach to

identify the critical system structure that will affect its interaction with the environment. New technology from a wide-ranging engineering discipline may be introduced to assist with the interaction or the decision-making process. A system life cycle process will be used to guide the system from conception to retirement and ensures that the objectives of the system are met throughout the entire life of the system. Using the attribute list as a guide, it is possible to begin the SE process.

D. OBSERVABLE AND NON-OBSERVABLE SYSTEMS

The determination of which objective or subjective validation techniques is necessary depends on whether the system is observable or non-observable. Robert Kalman (1959) originally defined for dynamic systems as "If a^*_j is not an observable costate, then the state x_i cannot be determined; in other words the plant's (system's) behavior cannot be inferred from the measurements" (486). Dahleh, Dahleh and Verghese (2011) further described an observable system as, "The initial state *x(0)* can be uniquely determined from the input and output measurements if the system is observable." Figure 7 graphically shows the determination of observable systems and NOSs as defined in the domain of control theory. Thought bubbles are added to compare each component of the figure to the M&S domain. Figure 7 presents a system with an unknown initial state. The inputs of the system are executed and outputs are produced. If the initial state of the system can be determined, then the system is classified as observable. It is classified as non-observable if a determination cannot be made.

Figure 7. Overview of Observable and Non-Observable Classification



1. Observable Systems

Sargent (2010) defines observable system, "as it is possible to collect data on the operational behavior of the problem entity during the execution of a simulation" (174). For observable systems, analysts are able to observe the behavior of the system during the operation of the model and evaluate the system throughout its execution. A physics-based model, such as a small unit force on force lethal engagement, can use laws of physics as its referent to forecast the behavior of the system and there is very little to no deviation from the expected effects to actual effects. If there are deviations, analysts can refer back to the original equations to identify any deficiencies. In such cases, the referent is implicit. The referent comes from the laws that have been used to represent past combat (Appleget , Blais, and Jaye 2012).

2. Non-Observable Systems

A NOS is the opposite of the observable system where it is not possible to collect data on the operational behavior of the problem entity. It is difficult to assess the quality of the model because there is not enough information about the system to understand its

behavior fully. This is especially true for models of systems that are nonexistent or in development for future operations. The quality assurance of the model is still a challenge even for existing systems that are not completely observable (Balci 1986).

The definition of a NOS in the M&S domain is not clear. Turner (2014) described NOSs as systems that do not facilitate the collection of data. In order to provide an example, Turner (2014) uses an anti-piracy operation scenario as an example of simulating a NOS. He identifies in the scenario that there is sufficient knowledge of the units conducting the operation. The uncertainty of the behavior of the pirates is too great to build a model to examine the results of the interaction (Turner 2014). Thus, there is a need for a non-traditional approach to modeling a NOS to overcome the uncertainty.

A future conceptual system can be classified as a NOS due to the lack of information about its components. It can be a current system where the interactions between the components are not observable. Examples provided in the most recent literature about a NOS are of non-physics-based systems interactions with external systems.

3. Validation of Observable and Non-Observable Systems

Sargent (2007) suggests that a NOS can be operationally validated using two different approaches, subjective or objective. Table 1 outlines Sargent's approaches to operational validity for NOSs. The objective approach cannot be used because for future conceptual systems, there are no other models to compare. In addition, with no data, statistical tests are meaningless. Even in the subjective approach, there would be no comparison to other models. Thus, the only method of operational validity of a NOS is through model exploration.

Table 1. Operational Validity Classification for Non-Observable Systems

	Non-Observable System
Subjective Approach	• Explore Model Behavior • Comparison to Other Models
Objective Approach	• Comparison to other Models Using Statistical Tests

Sargent, Robert. 2007. "Verification and Validation of Simulation Models." *Proceedings of the 2007 Winter Simulation Conference*: 130.

An observable system also uses objective validation techniques for validation. An operational validation for an observable system is achieved when the outputs match the expected output that supports the fundamental objective. For a NOS, the outputs do not match the expected outputs. Therefore, in a NOS, the COM is evaluated to conduct model exploration.

The model of the system is determined to be a failure after multiple iterations of the simulation and never meets the expected output. The model may never converge to determine the initial state of the system due to not knowing which function prevents outputs from matching the expected output. Buede (2009) describes the failure of a system is determined when the process is also not observed and the system does not maintain a copy of its requirements. A point of fault cannot be determined and a new system must be created to address the deficiencies.

E. SYSTEMS ENGINEERING

Buede (2009) defines systems engineering as "engineering discipline that develops, matches, and trades off requirements, functions, and alternate system resources to achieve a cost-effective, life-cycle-balanced product based upon the needs of the

stakeholders" (10). There are eight functions listed by Buede (2009) quoted here as an overview of the complete SE process:

0a Define the problem to be solved

0b Define and evaluate alternate concepts for solving problem

1. Define the system-level design problem being solved
2. Develop the system functional architecture
3. Develop the system physical architecture
4. Develop the system allocated architecture
5. Develop the interface architecture
6. Define the qualification system for the system (51).

This research uses the last six functions to investigate the concept of non-observable systems and to build its architecture.

1. Systems Engineering Process

A system simply does not appear, as it goes through a methodical SE process to ensure that the system works and meet the stakeholders' needs. A very important aspect of SE is its relationship to the system life cycle. There are many examples of systems life cycle models in literature, but the most common aspects are conceptual design, development, production, training, operations and maintenance, refinement, and retirement.

SE is multidisciplinary in the fact that it involves the integration of knowledge and best practices from different disciplines into the development and an interconnected and interrelated system. The engineering of integrating these components and ensuring that the system meets the needs of the stakeholders is what makes SE unique from other engineering disciplines.

INCOSE notes that the SE process has an iterative nature that supports learning and continuous improvement (SE Handbook Working Group 2011). It is during the

engineering process that the analysts gain a better understanding of the stakeholders' needs and apply this knowledge to the design and the functionality of the system. The analyst may discover unexpected or emergent properties as the system performs its functions and interacts with its elements, external systems, and environment. This can be attributed to the complexity of the system. By using the SE process, analysts are able to develop the design and integrate the components to create an effective system that enables the public to trust the banking system and continue to deposit their money at their local banks.

One of the standards that analysts use is the military standard 499B (1993), as it defines the engineering of systems as "an interdisciplinary approach encompassing the entire effort to evolve and verify an integrated and life cycle balanced set of system people, product, and process solutions that satisfy customer needs" (Department of Defense 1993, 40). In the technical draft, quoted below, it states that SE encompasses the following:

- Technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for system products and processes
- The definition and management of the system configuration
- The translation of the system definition into work breakdown structures
- The development of information for management decision (Department of Defense 1993, 40)

The SE process has key concepts that must be reviewed to design a NOS. Each concept is a building block for designing overall systems architecture of a NOS.

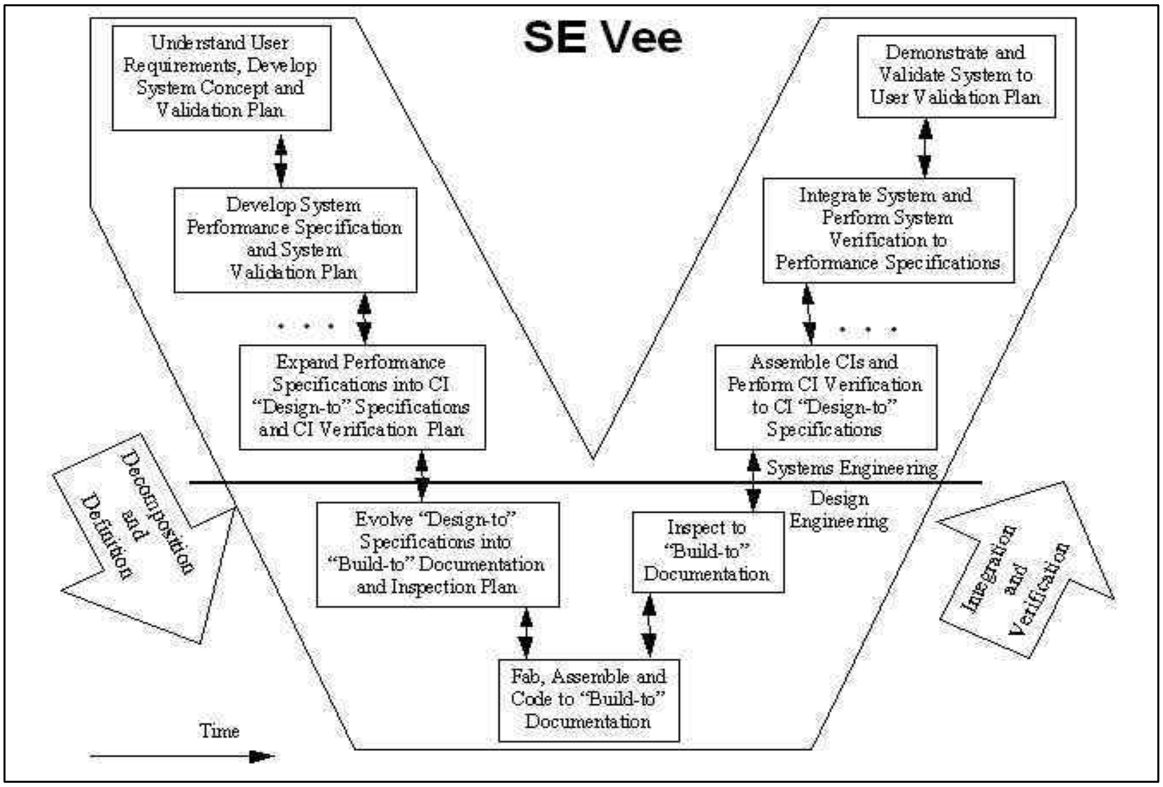
Buede (2009) defines operational concept as a "vision for what the system is (in general terms), a statement of mission requirements, and a description of how the system will be used" (481). The operational concept provides an overall view of how the system will interact with the external system. A military example of an operational concept would be the purpose of a military mission and how it will interact with the enemy or local populous. An external systems diagram establishes the boundaries of the system and the external systems with which it may interact. Objectives hierarchy is the hierarchical

list of objectives that must be met. The hierarchy is based on the requirements and values of the stakeholders. Requirements are defined as the tasks that must be completed to meet the stakeholders' needs. Functions are the action that the system performs to produce the intended effects, and they serve as the foundations of building a functional architecture, which is discussed in more detail later in this chapter. Items are the inputs that go into the system. Components are the physical aspect of the system. It is the physical items that perform the functions. Interfaces are where components and systems are connected. It is the location where components and systems interact with each other. It is in these spots where observations may not happen during initial testing of a system.

2. The Vee Model

There have been several different processes developed to assist with engineering a system. Figure 8 shows the "Vee" process, which describes SE as being composed of decomposition of a system followed by the integration to improve the system. The left side of the Vee is the decomposition of the system that presents three phases of understanding the requirements, developing the system performance specification and system validation plan, and expanding the performance specifications into a configuration item verification plan. Decomposition is the "hierarchical, functional and physical partitioning of any system into hardware assemblies, software components, and operator activities that can be scheduled, budgeted, and assigned to a responsible manager" (Forsberg, Moos, and Cotterman 2005, 110). The Vee model's focus on decomposition and design is to improve the understanding of the operational needs and translate it to system-level requirements (Buede, 2009). Also, note that the decomposition is conducted from the overall system to subsystems to entity levels. It is through this decomposition that the system can be identified to its entities to correct errors and fill gaps.

Figure 8. The SE "Vee" Model



Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 10.

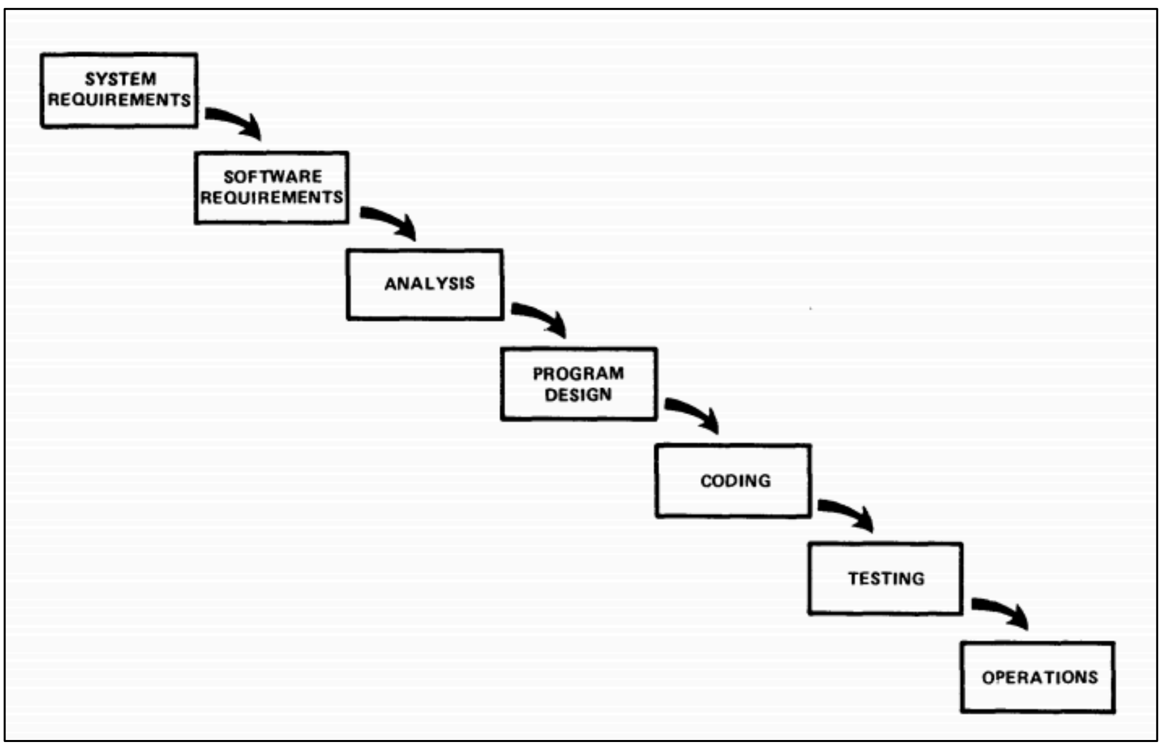
The horizontal line shows where the analysts mentioned earlier take the requirements and produce the physical aspects of the system (Buede, 2009). The conceptual model of the system developed on the decomposition side of the Vee is the "blue print" the other analysts will follow to develop a physical system and begin its integration. As mentioned previously, the conceptual model must be created with limited errors and gaps filled to reduce the overall cost of creating the system.

The right side of the Vee is the integration and verification of the system. This is where the system is put together from its entities to sub-systems to the overall system. The system is tested to ensure that all of the elements are in compliance and meet the stakeholders' satisfaction.

3. The Waterfall Model

The waterfall model developed by Dr. Winston W. Royce is another widely accepted SE model. As seen in Figure 9, the waterfall is a linear model that is very risk adverse (Forsberg, Mooz, and Cotterman 2005, 106). Unlike the Vee, the waterfall is easier to understand due to its simplicity. This simplicity makes the waterfall lacks some important aspects of SE, such as the integration of specialists to create the model of the physical system for integration, verification, and validation. The waterfall is a linear path from top to bottom from the system requirements phase to operations and maintenance. It leaves little opportunity to introduce new ideas during the development process. The waterfall does allow changes by conducting a backward iteration to change its baseline. Because the model emphasizes the flow down of progress, going backward is not cost effective and it is difficult to repeat steps.

Figure 9. The Waterfall Model

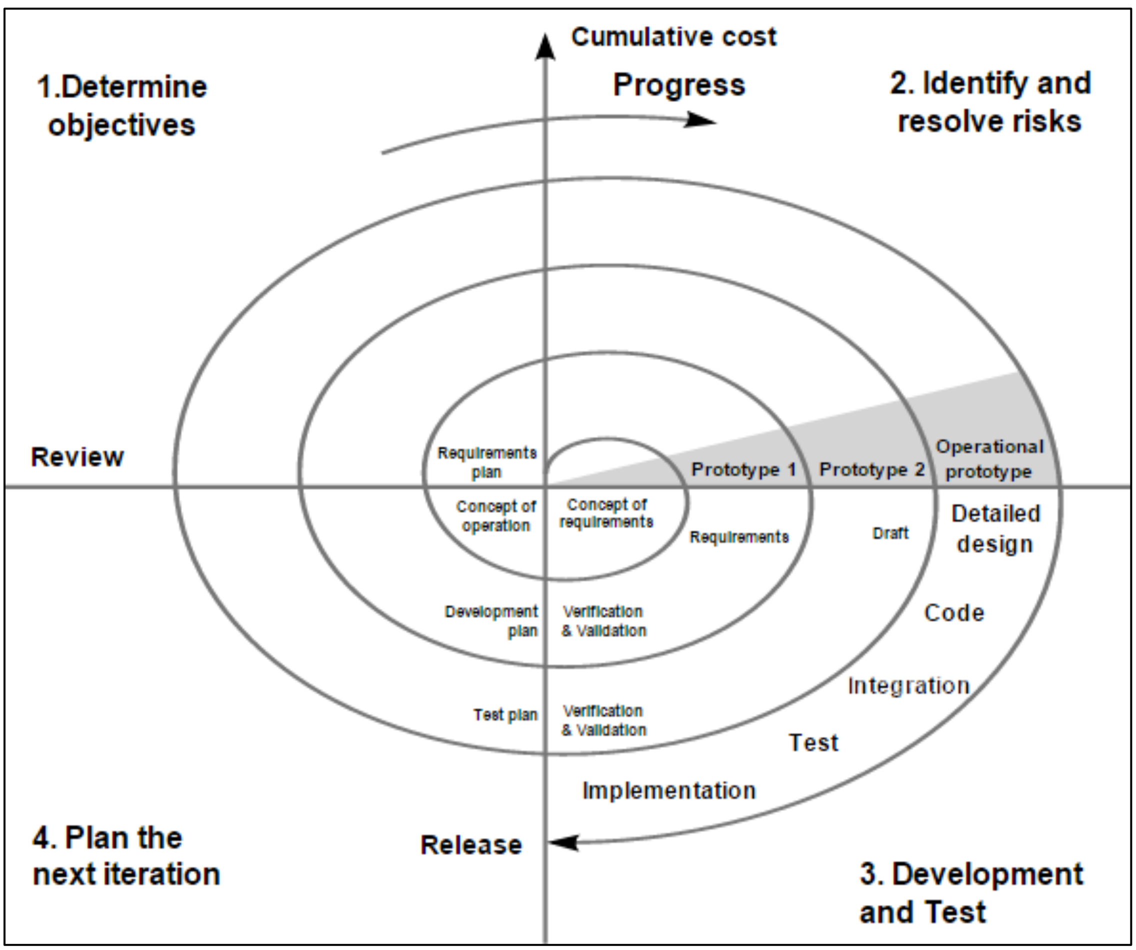


Source: Royce, Winston W. 1970. "Managing the Development of Large Software Systems." *Proceedings of IEEE WESCON*, 329.

4. The Spiral Model

The spiral model was created to improve on the developments of the waterfall model and to improve the process. The spiral, unlike the linear waterfall, as the name attests is non-linear and emphasizes repeatability during its development process. Figure 10 shows the spiral model presented by Boehm (1988). In Boehm's model, each spiral is in essence an iteration of the waterfall model (Parnell, Driscoll, and Henderson 2011). The spiral also introduces the concept of risk analysis throughout its cycle. The system must successfully mitigate identified risks at each phase to move on to the next phase. Failure to resolve any risks can lead to delays or even termination of the overall system.

Figure 10. The Spiral Model



Source: Boehm, Berry W. 1988. "A Spiral Model of Software Development and Enhancement." *Computer*, 64.

The three SE process models all present different ways to develop a system. However, they all share the characteristics of identifying requirements, design, development, maintenance, and retirement. Although the analyst is involved in all the phases during the SE process, the design phase is where they are mostly involved.

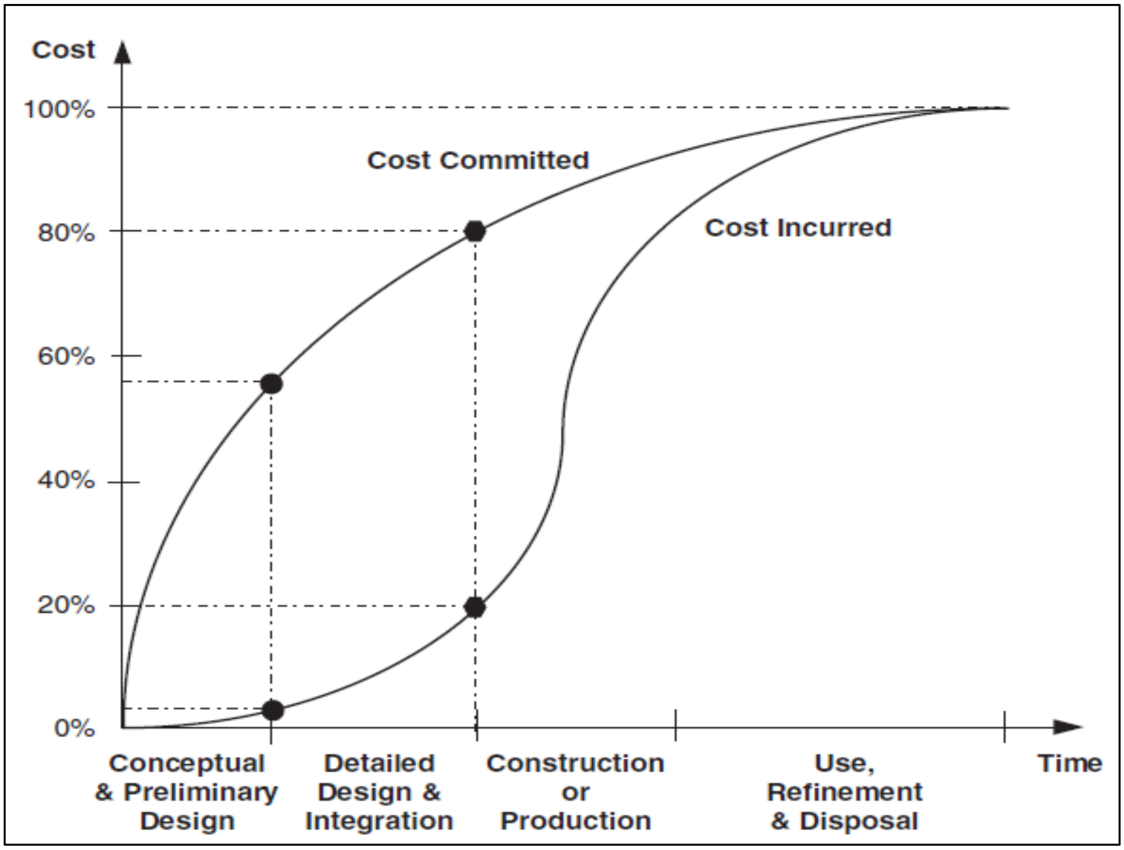
F. SYSTEMS DESIGN

Buede (2009) describes system design as transforming stakeholders' ideas of systems into visual models by engineers. Designing a system requires several steps. A system is decomposed, requirements identified, and the architectural representation of the system created (Buede 2009). Turner's (2014) research identified that designing models of NOSs for simulation needed more research into the proper development of its structure.

Blanchard and Fabrycky (2010) explain that the basis of establishing the structure of a system starts with the design of the system. The design is an analyst's vision of how the system will meet the requirements identified by the stakeholders (Blanchard and Fabrycky 2010). The design of a system takes form as early as the initial interaction between the stakeholders and the analyst. The initial design is not the final design and the traceability of its effects to the objectives.

Figure 11 illustrates the importance of ensuring a well-designed system early in the life cycle process. The X-axis represents the life cycle phases and the Y-axis represents the percent of the cost of developing the system. The programmed cost of the cost committed curve has a steady increase to 100% while the actual cost incurred displays a steep rise during the construction and production phase. At the end of the "detailed design and integration" phase, the cost committed is at 80% while the incurred cost is only 20%. Ensuring that the system's functions, components, and interfaces are clearly defined and are traceable to the requirements outlined by the stakeholders is important to ensuring that costs, no matter how it is defined, are reduced for developing a system.

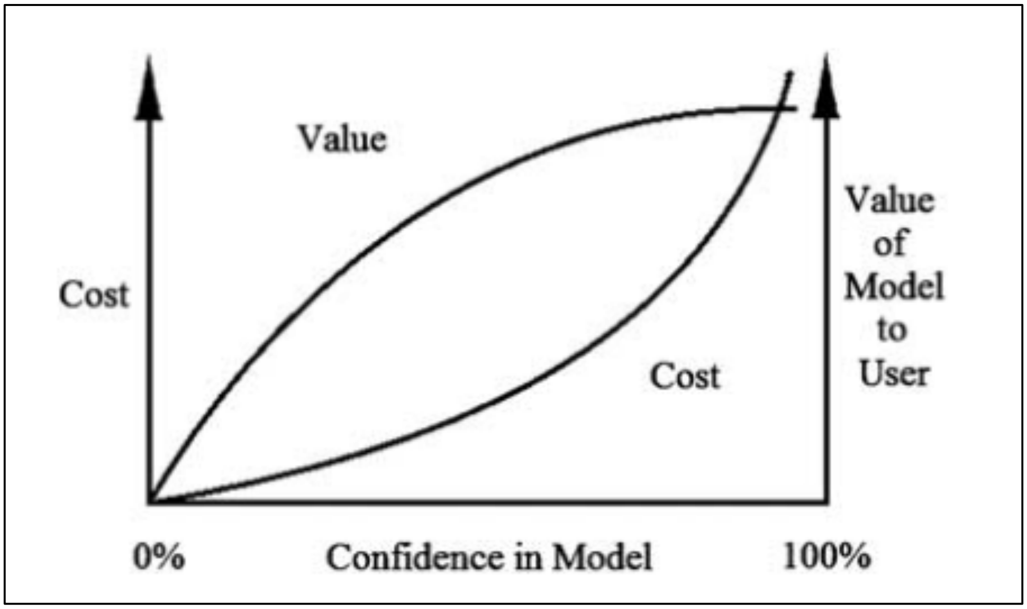
Figure 11. Systems Life Cycle versus Cost



Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 8.

The systems cost curve is also in line with Sargent's model of cost versus value as seen in Figure 12. As the confidence in the model increases, both the value and the cost also increase (Sargent 2010). However, examining the cost and value curves, the two curves intersect, which indicates the return on the cost is not worth the value of the model. Sargent (2010) states that the cost of the model may not justify the attempt for absolute validation of a model. Thus, improving the methods of existing validation methods are ways to ensure that the cost of the model meets the values of the stakeholders.

Figure 12. Confidence that Model Is Valid



Source: Sargent, Robert. 2007. "Verification and Validation of Simulation Models." *Proceedings of the 2007 Winter Simulation Conference*, 125.

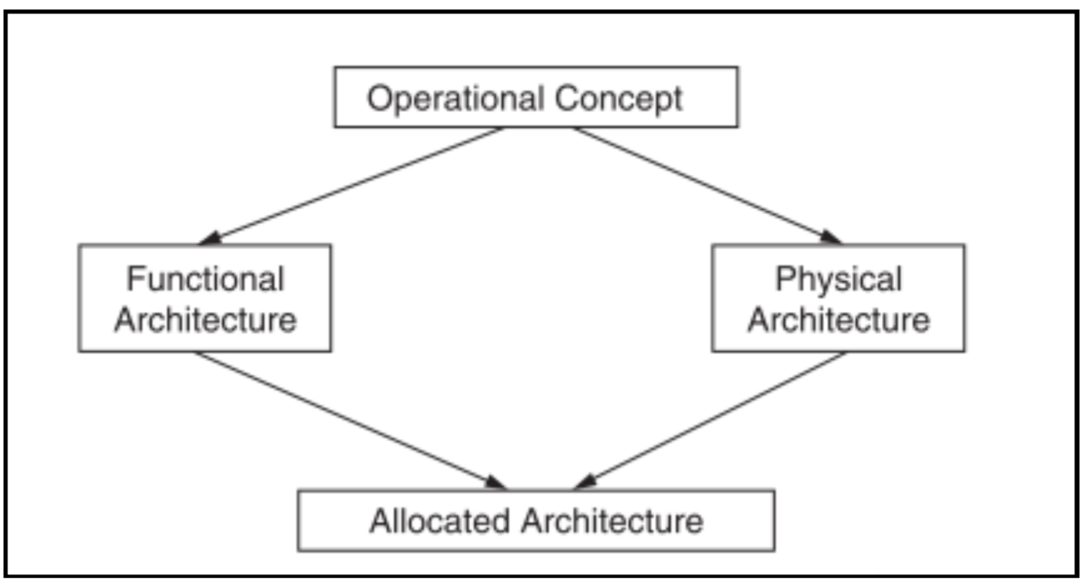
A well-designed conceptual model will improve the structure to ensure that the effects of the system are traceable and support the validation of the NOS. Using the Vee model discussed earlier, the design phase is primarily focused on the left side or the decomposition side of the Vee model. Architecting is an important aspect of system design. Architecting techniques are used to decompose the system into functions, components, and allocation. The next section provides an in-depth review of architecting. The right side of the model describes the integration and the qualification of the system. During this phase, the model of the system goes through the verification and validation phase to ensure that the system design decomposed on the left side supports the defined requirements.

G. SYSTEMS ARCHITECTING

The term architecture has traditionally been related to physical buildings. It is the way people have been designing and constructing structures throughout history. Systems engineers have borrowed architecting concepts to solve the difficulties of designing complex systems (Maier and Rechtin 2000). Architecting is a way for analysts to

decompose the system to translate the needs of the stakeholders and the solutions of how the systems will satisfy the needs. During the design phase, or the left side of the Vee model, three types of architectures, the functional, physical, and allocated, are used for the decomposition process (Levi 1993). Figure 13 depicts Levi's (1993) architecture development model as outlined by Buede. The architectural development process starts with the operational concept. Buede describes the operational concept as an overview of the system. The operational concept describes the mission, requirements, and the execution of the system. Functional, physical, and allocated architectures are developed as part of the decomposition of the system (Buede 2009). The functional architecture describes what the system will do. The physical architecture depicts what components are available in the system. The allocated architecture is the mapping of functions to components (Buede 2009). It is important that all three of these models are developed independently to identify the functions and the components that perform the functions to integrate the two architectures.

Figure 13. Architecture Development in the Engineering of a System



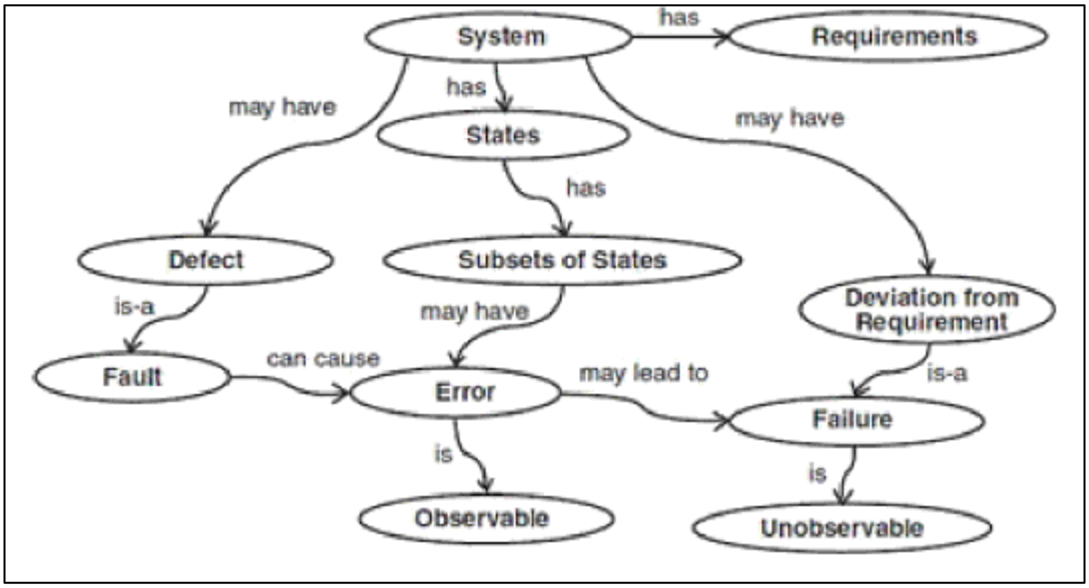
Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 28.

Architecting is an important tool the analyst will use to decompose the NOS to allow traceability of the effects. The combination of the architectures helps to answer which component with which functions had the greatest impact on the results of the system.

1. Functional Architecture

The *Merriam-Webster* dictionary defines the term function, "as the special purpose or activity for which a thing exists or is used" (Merriam-Webster 2015). For our purposes, it is possible to substitute the word "thing" with system. It is what the system will perform at its basic definition. A more comprehensive definition provided by the INCOSE defines the term function as, "A characteristic task, action, or activity that must be performed to achieve a desired outcome" (INCOSE 2003, 281). Functions may be accomplished by one or more components of the "system comprised of equipment (hardware), software, firmware, facilities, personnel, and procedural data" (INCOSE 2003, 123). Buede (2009) also defines the term function as, "a process that takes inputs in and transforms these inputs into outputs." Combining INCOSE's and Buede's definitions provides a robust understanding of the term function. A function is when a system takes inputs in, which are tasks, actions, or activities, and the output should be the desired system behavior. However, when the output of the function deviates from the desired system behavior, an error or failure may occur. In the fault-tolerance community, an error is determined when the system is able to observe the changes of the system. Since an error is observed, it can be identified and corrected. However, an analyst normally is not able to monitor the entire state continuously, as not all errors are able to be observable, which leads to system failure. A failure in the system is an unobserved deviation from the system requirements. Figure 14 depicts a concept map for fault tolerance terms as described by Buede.

Figure 14. Concept Map for Fault Tolerance Terms



Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 243.

A functional architecture enables the analyst to organize the many functions the system must perform. It does this by decomposing the system's top-level function and outlining what they system must do. It is the functional architecture that allows the "hierarchical arrangement of functions, their internal and external functional interfaces, their respective functional and performance requirements, and the design constraints" (INCOSE 2004, 124).

The functional architecture outlines the tasks of the system. One of the ways is with a model of a functional hierarchy showing the functions to be performed by the system and its components (Buede 2009). Another use of the functional architecture is capturing the transformation of the inputs, outputs, controls, and the mechanisms of the system.

To build a functional architecture, an analyst must perform several steps. First, the analyst must define the system's functions by conducting a functional analysis. A functional analysis is conducted to identify the required functions of the system and its internal and external interfaces. It is one of the earliest processes to be performed in the

system life cycle. There are several methods to perform functional analysis. The output of all functional analysis is the identification of system functions and interfaces (Parnell Driscoll, and Henderson 2011). Parnell, Driscoll, and Henderson (2011) list four main functional analysis techniques: Functional hierarchy, functional flow diagram, IDEF0, and modeling and simulations. IDEF0 and modeling and simulations are discussed in more detail later in the chapter.

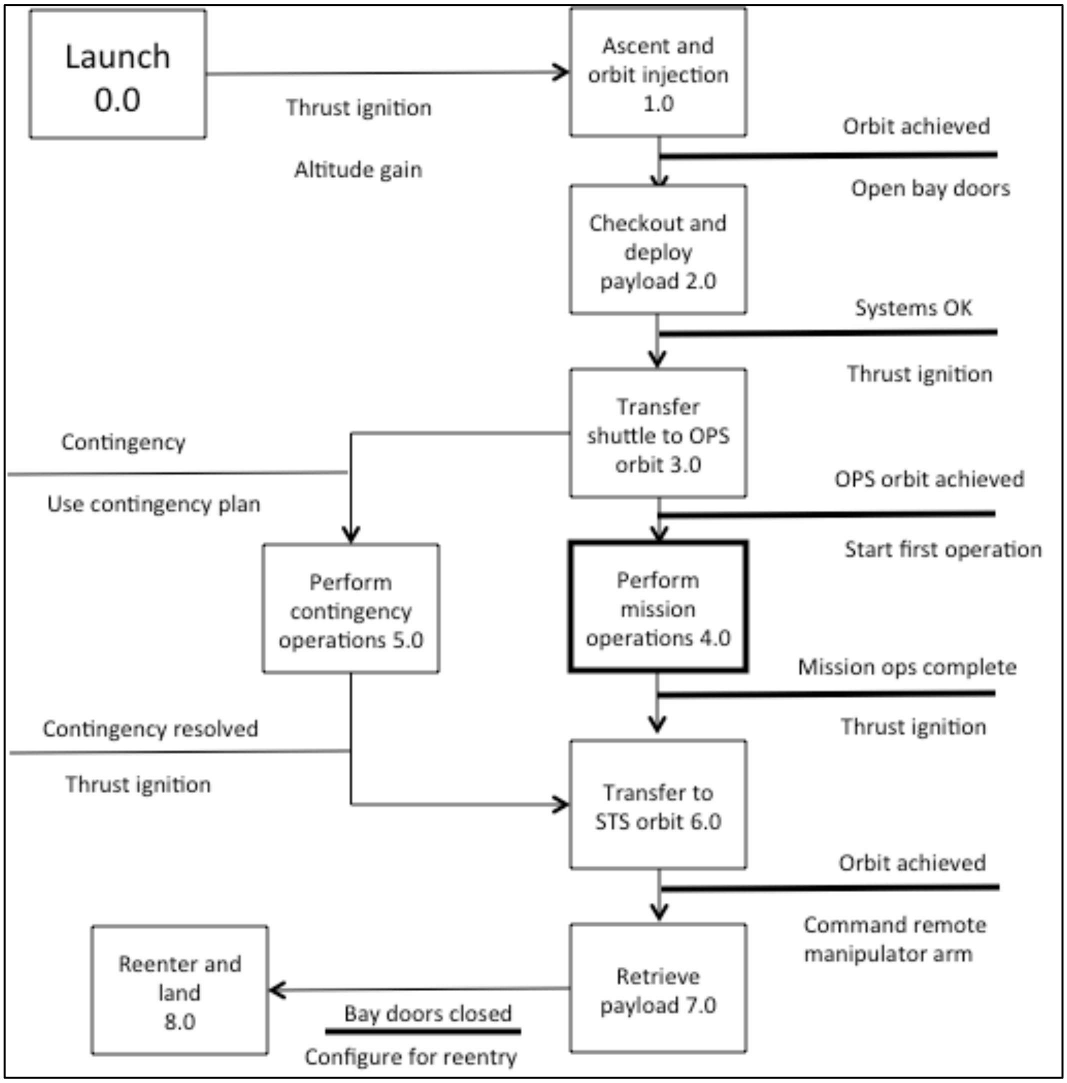
a. Functional Hierarchy

A functional hierarch provides an understanding of the functions that the system must perform from top to bottom. It is the foundation of more detailed functional analysis conducted throughout the life cycle (Parnell Driscoll, and Henderson 2011). The functional hierarchy does not identify interrelationships between system components.

b. Functional Flow Diagram

The relationships between the components can be depicted on a functional flow diagram (FFBD) after completing the functional hierarchy. Defining all of the relationships within a system supports a detailed functional decomposition. Figure 15 is an example of a FFBD of the National Aeronautics and Space Administration's (NASA's) Space Transportation System (STS) Flight Mission (Parnell, Driscoll, and Henderson 2011). However, the limitation of the functional flow diagram is the inability to identify interfaces of the components. An enhanced functional flow block diagram (EEFBD) represents three critical aspects of systems modeling: flow, data interactions and resources. An EFFBD is a variation of the FFBD that also represents the behavior of a system (Buede 2009, 93).

Figure 15. Functional Decomposition for the Top Level of the STS Flight Mission



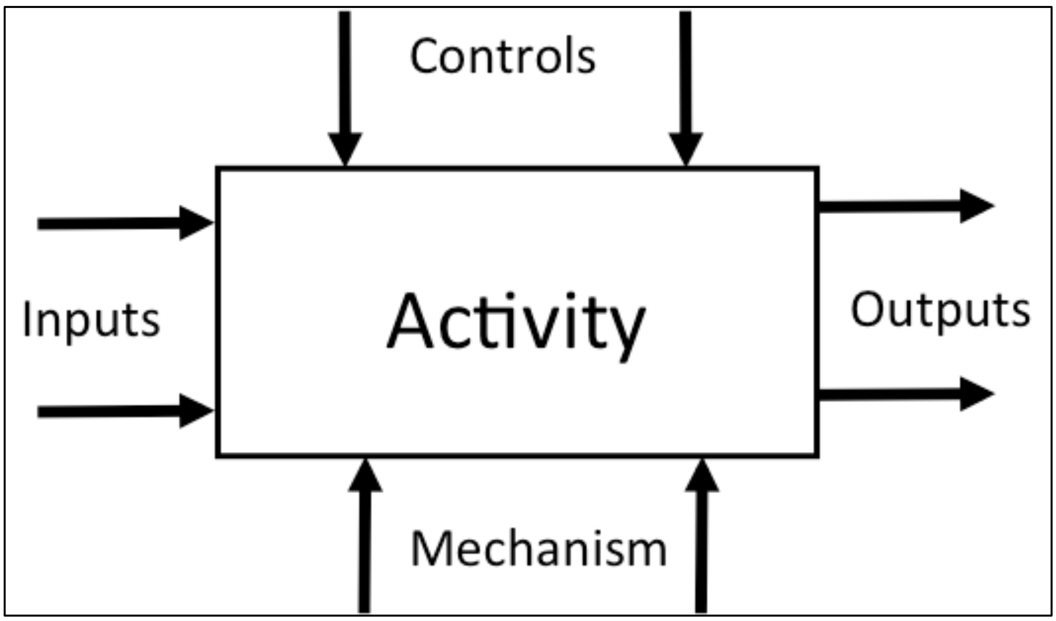
Source: Parnell, Gregory S., and Driscoll, Patrick J., and Henderson, Dale L. 2011, *Decision Making in Systems Engineering and Management.* Hoboken, NJ: John Wiley & Sons, 321.

c. *Integrated Definitions for Functional Modeling 0*

The IDEF0 model provides the alignment of functions to components. The IDEF0 language is a method of describing the system's processes and activities. There are 14 methods in the IDEF suite. IDEF0's purpose is for modeling functions. IDEF0 is a method of functional decomposition inputs, controls, outputs, and mechanisms (ICOM) that address the interaction of the system with other systems. It can describe the

hierarchical functions of the system with the IDEF0 hierarchy, and starts at A0 with the first tier functions to A1, A2…Ai, the second tier, and A11, A21…Aij, the third tier functions (Parnell, Driscoll, and Henderson 2011). The IDEF0 models are used to decompose a system to show stakeholders all of the ICOMs that are involved in performing a function.

Figure 16. A Generic IDEF0 Model

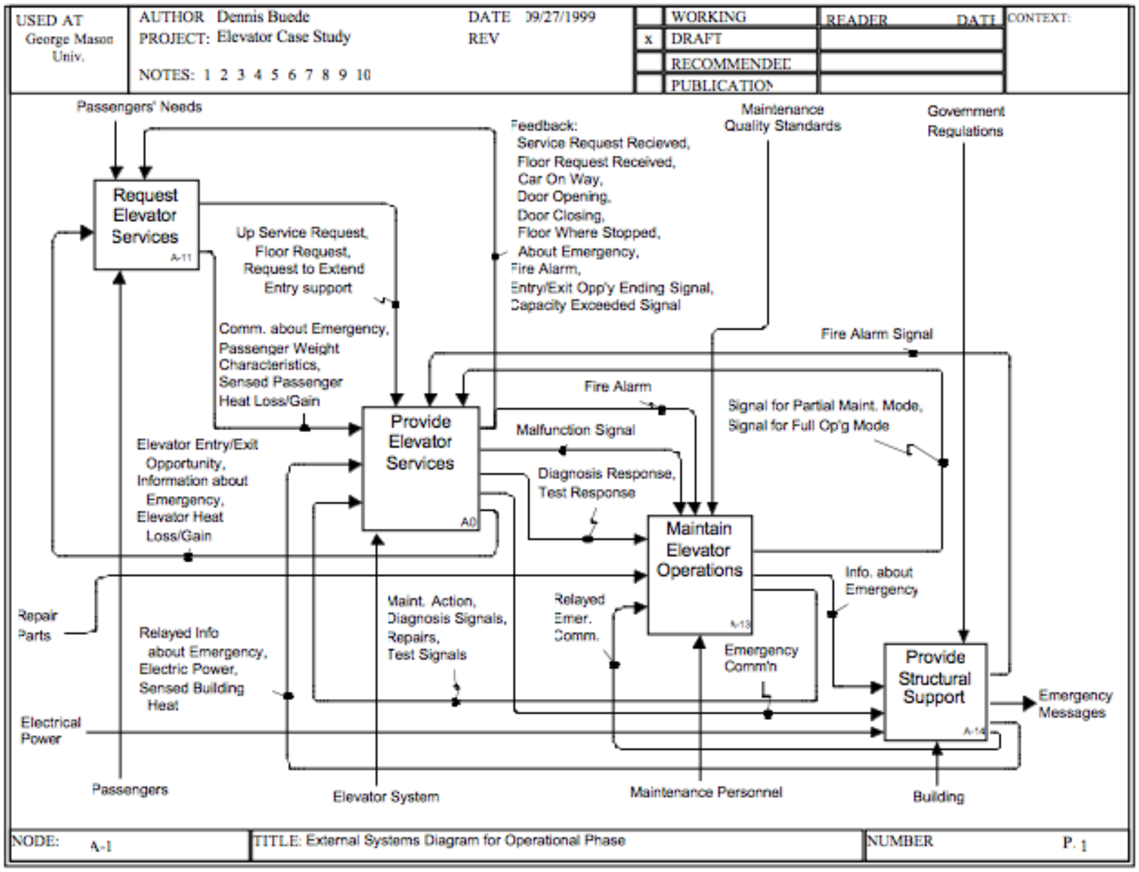


Source: Parnell, Gregory S., and Driscoll, Patrick J., and Henderson, Dale L. 2011, *Decision Making in Systems Engineering and Management.* Hoboken, NJ: John Wiley & Sons, 44.

Figure 16 shows a basic building block of an IDEF0 model. The box represents a function that the system will be performing. The arrows coming down from the top represent the controls that specify the conditions needed for the function to perform. An example is a rules of engagement directive in Afghanistan. It dictates how military personnel react to contact. The arrows on the bottom are the mechanism that performs the functions. The identification of the mechanism to the function is important to creating the allocated architecture. The arrows on the left coming into the box are the inputs. They are the current state prior to the function being executed. The arrows leaving the box are the outputs that are transformed as a result of the execution of the function. The outputs may also be an input to

other functions within the IDEF0 (Parnell, Driscoll, and Henderson 2011). Figure 17 shows a more complex IDEF0 model of an elevator system.

Figure 17. Elevator System External Systems Diagram for Operational Phase



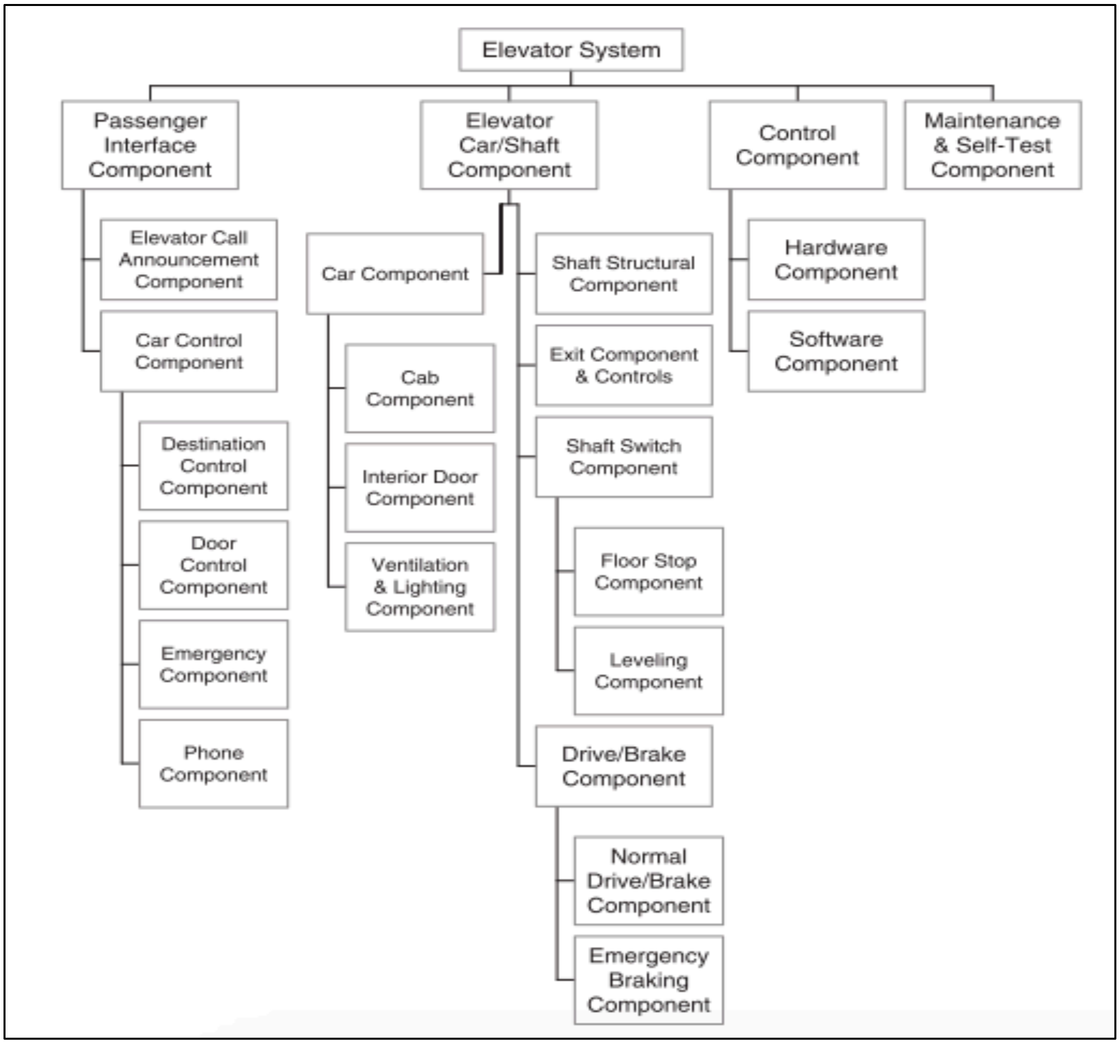
Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 58.

2. Physical Architecture

An important aspect of architecting is to understand which components will perform the functions required of the system, which can be achieved by the development of the physical architecture. The physical architecture of a system is the description of the components that make up the system (Buede 2009). It is hierarchical, like the functional architecture described earlier, and helps the analyst to view the overall system down to its basic components.

There are two ways to view physical architecture, generic and instantiated. Figure 18 is a generic physical architecture of an elevator from Buede's elevator case study. It depicts the components that make up the elevator. A generic physical architecture outlines the hierarchy of the components of the system. Instantiated physical architecture provides a more detailed description of the components to enable performance modeling of the system.

Figure 18. Generic Physical Architecture from the Elevator Case Study



Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 256.

A morphological box is one way to assist in developing the physical architecture. It is a technique using a matrix to list the components of the system. It is used to break down a system into segments as defined by the generic physical architecture. Then, details about the components are filled in to complete the matrix. The detailed box becomes the instantiated physical architecture (Buede 2009). The morphological box allows the analyst to see the details of each of the component and create the best combination for the system. For instance, the example shown in Table 2 is of a vehicle needed for a mission. Components of the vehicle would be listed on top.

Table 2. Example of a Morphological Box for a Vehicle

Tire Size	Gas Tank Size	Engine Size
16"	10gal	4 Cylinder
18"	15 gal	6 Cylinder
20"		8 Cylinder

The tire size, the gas tank, the engine size would be some of the components for consideration of a vehicle. Based on this example, there would be 3x2x3=54 different vehicle combinations to consider. A real world consideration for a vehicle would have many more combinations.

3. Allocated Architecture

The final piece of architecting is the development of the allocated architecture. The allocated architecture is the integration of the functional architecture and the physical architecture to ensure the right components are doing the right functions. It also defines how the system will interact with the external systems. It is important that the architecture meets the requirements of the stakeholders and gains their approval. The allocated architecture will provide the overall description of the system.

The allocated architecture will be used to model the entire system. This architecture will provide the traceability of the system effects to its objectives for NOSs.

Traceability of the model would help identify the cause of deviation from the intended system effects and actual system effects.

H. RECENT MODELING OF NON-OBSERVABLE SYSTEMS FOR SIMULATIONS

Turner's research in 2014 is the one of the first known work on modeling of a NOS for simulations. Turner (2014) proposes the following method to address the current gap in literature of an approach to decompose the system, identify relationships that impacts the system in a traceable and defensible manner.

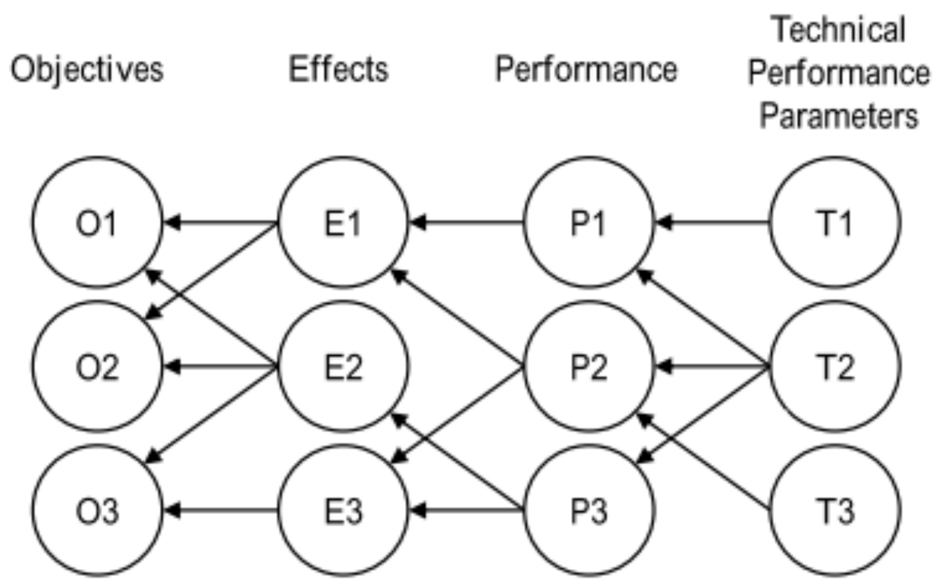
- Utilize SMEs to decompose the system and assign impact relationships between measures
- Determine importance of relationships through analysis
- Based on relationship importance, decide how the entity is represented and to what fidelity based on a selection scheme
- Compare results to impact relationships (Turner 2014, 105).

As mentioned earlier in the chapter, decomposition of the system is an important aspect of the SE process. SE has several methods of decomposing a system. The two basics are functional and physical decomposition to understand what functions the system will perform and which component will perform them.

Turner (2014) uses a mathematical graph presented by Green (2001) during a Military Operations Research Society (MORS) on measures of effectiveness for command and control. The approach uses a mathematical graph to show the different levels of a system. The top level is the objective. The objective defines the purpose of the system and the desired behavior. The following level is the effects level. It is defined as the measurement of how the system performs within a larger system. The level below is performance. Performance measures the individual components tasks, e.g., range and speed. The final level is the performance parameters. It is the characteristics of the system, such as the weight of the vehicle and the wingspan of an airplane. Turner (2014) points out that the impact travels from the lowest level of technical performance to the highest level, the objective. Figure 19 outlines the different levels and the flow of impact.

The mathematical graph identifies the levels as the nodes that represent the metrics, while the edges represent the relationship between the two levels.

Figure 19. System Decomposition Graph



Source: Turner, Andrew. 2014. "A Methodology for the Development of Models for Simulation of Non-Observable Systems." PhD diss., Georgia Institute of Technology, 107.

As we follow the edges beginning with T1, it may have an impact on the performance of P1. The performance measured at P1 may impact the effects at E1. Finally, the effects at E1 may have an impact of achieving the objectives at O1 and O2. Each impact is how the different metrics are related to one another. The impact relationships are relating to the contribution of lower-level metrics to higher-level metrics that when summed equal unity. It is a SME defined relationship between the different levels (Turner 2014). Although the mathematical graph provides a visual of the relationships present in the system, it does not represent a functional hierarchy as discussed, or the decisions, processes and activities of an organization like an IDEF0 model (Parnell Driscoll, and Henderson 2011). An IDEF0 model is a much more robust method of visually representing a decomposed system.

I. GAPS IN CURRENT RESEARCH

Turner's (2014) work on modeling of NOSs for simulations is significant because it is unique. All other references to a NOS in the body of literature have been to define the term and the concepts, not how to build the models or validate them for system use in the real world. Turner (2014) identifies a need for an approach to decompose a system. Based on the limited information within the body of knowledge of modeling NOSs, Turner assumes that decomposing a system helps to identify the relationships between the metrics that have the most impact on the system. He uses a mathematical graph to display the relationship between metrics.

Finally, Turner (2014) identifies two areas of continued work in the field of modeling of NOSs for simulation at the end of his research. It is in these areas where further contribution to the body of knowledge is made and provides the following:

- Better transition from system definition to impact variable decomposition
- Proper development of structure for decomposition

Again, SE methods will be used in this research to continue the previous work to improve the method of validation of models of NOSs so it is traceable and support current SME validation methods.

J. VALUE MODEL

Value modeling provides a quantitative model that provides stakeholders feedback on what they value as the most important functions of the system. The value modeling process provides an opportunity for stakeholders to become more involved in the model development. For this research, the value model is used to assess the impact of the functions on the entire system given the weight placed on the function by the stakeholders.

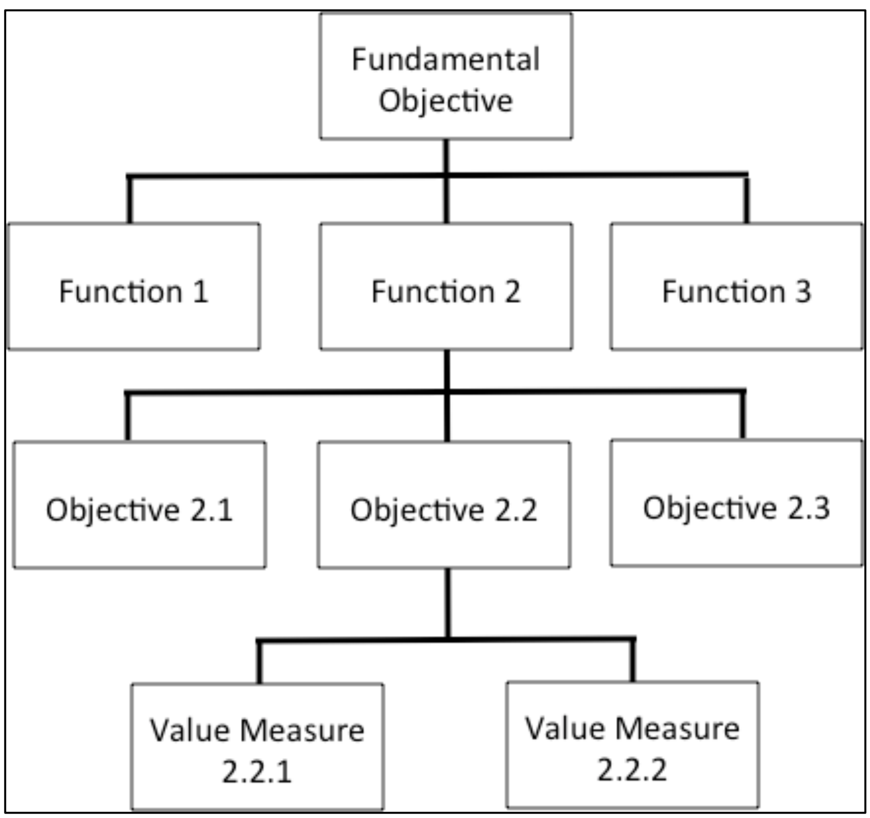
The value model built for this research uses the functional analysis to determine functions, objectives, and measures. Parnell, Driscoll, and Henderson (2011) define steps to creating a value model as quoted here:

- Identify the fundamental objective
- Identify functions that provide value

- Identify objectives that define value
- Identify value measures
- Discuss the value model with key stakeholders (327).

The value hierarchy is created using the steps identified above. Figure 20 shows the structure of a value hierarchy. The fundamental objective is at the top. The next level shows the functions required to be performed to meet the functional objective. The objectives below the functions provide a preference of whether the stakeholders want to maximize or minimize the objectives that define the value. The lowest level is the value measures that are aligned with the objectives. The values measures can be collected either directly or by proxy (Kirkwood 1997). Proxy measures would be taken for the effects of the interaction between the system and the external system because it is non-observable.

Figure 20. Structure of a Value Hierarchy



Source: Parnell, Gregory S., and Driscoll, Patrick J., and Henderson, Dale L. 2011, *Decision Making in Systems Engineering and Management.* New Jersey, John Wiley & Sons, 329.

K. SUMMARY

The M&S community continues to find ways to meet the challenges of modeling complex systems that are difficult to predict. Several MDPs are presented in the literature; however, the commonality among all of the MDPs is the need for a conceptual model validation. The need for a well-structured and validated CoM takes even more prominence during the operational validation of NOSs. The concept of a NOS is not well defined within the M&S domain. Other fields, such as control theory and fault tolerance domains, have used the term in similar ways. Control theory uses observability to address the internal state of the system inferred by its outputs (Kalman 1959). Fault tolerance uses it to describe a failed system where the system is unobservable because it does not keep a record of its requirements (Buede 2009). Sargent (2010) applies the term NOS "as not possible to collect data on the operational behavior of the problem entity (system), thus there is not a high degree of trust in the model." Other examples in literature refer to future systems with little or no knowledge to be designed, modeled and validated as NOSs.

Current methods of validation of NOSs have primarily been through subjective validation techniques, such as face validation (Turner 2014). There is a need to find another method of validating models of systems by ensuring it is traceable and defensible. Recent attempts at modeling NOSs for simulation have reinforced the importance of a well-structured CoM. This research is the first known attempt to ensure that multiple validation methods are used for building COMs of systems to support operational validation ensuring traceability and defensibility. The use of SE processes improves the modeling of these systems for validation. The SE process uses functional and physical decomposition methods to identify relationship and use allocated architecture to ensure system functions are performed by the correct component. While the mathematical graph is a simple way to identify how lower level of metrics affects the higher, SE models, such as the IDEF0 model, shows the complexity of a system in greater detail. Finally, a more analytical method of assigning impacts of the different functions and components is the use of the multi-objective decision analysis (MODA)

techniques. SMEs are still heavily involved in a MODA and have a method of tracing their values to the model.

Finally, Buede's (2009) description of the interactions of the system to external systems provides a visual of the system and how it impacts the external system. This interaction occurs during the execution of the simulation during the MDP. The validation of the CoM improves the expectation of the system prior to the execution of the simulation. The improved understanding ensures analysts and DMs are able to interpret the results of the simulation even with limited or no observation of system's behavior during the simulation. Using Sargent's (2001) MDP and SE concepts as a foundation of understanding improves the conceptual model traceability to the components, and facilitates greater SME involvement with conceptual model development. The end product is a validated model of a system, in which DMs can rely on to make critical decisions.

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III. IMPROVED CONCEPTUAL MODEL METHODOLOGY

The ICoMM introduced in this dissertation focuses on improving the structure of the CoM during the MDP. The improved structure better facilitates the use of face and traces validation techniques for CoM validation and supports operational validation of NOSs. The basis of this method is the continuation of previous research on development of models for simulations of NOSs by Turner (2014). In 2014, Turner states that his research lacks a clear methodology to improve transition from system definition to impact variable decomposition. Turner (2014) defines impact variables as “the relationship of lower level metrics contributing to higher-level metric” (111). He also identifies the need to conduct further research into proper development of its [model] structure (Turner 2014).

ICoMM improves the structure of the conceptual model by SE and SA to Sargent’s evolved MDP. A model is a representation of a system. ICoMM presents the idea that SE processes should be used to build the model of a system. SE “focuses on identifying customer needs and functionality early in the development process, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem” (INCOSE 2015). A CoM describes system functions and the execution of the functions to achieve the fundamental objective (Law 2007). SE and SA methods support the ICoMM by identifying the components of their interfaces and concept of execution.

The value of ICoMM is an improved structure of the CoM that facilitates the identification of a single fundamental objective, early inclusion of SMEs, and identification of external system functions that affects the fundamental objective. Identification of a single fundamental objective focuses the system and its components to one overarching objective. ICoMM reduces the confusion of performance measurements leading to multiple objectives by facilitating traces of measurements and sub-objectives leads to the fundamental objective. All the components are aware of its contribution towards fundamental objective. SMEs are required for the development of the CoM early in the MDP. SMEs weights of functions are documented and then evaluated at the end of

the simulation. The CoM must be reevaluated if there is a deviation from the actual output from the output envisioned by the DM. The first item to be investigated is the weights of the functions provided by the SMEs. The SMEs are held accountable by the weights of the functions assigned by the SMEs. The identification of the external system shows the potential of how the external system interacts with the system to either enhance or degrade the achievement of the fundamental objective. The interaction between the two systems may be non-observable; a well-structured CoM helps to identify points of interaction.

A. CONCEPTUAL MODEL DEVELOPMENT PROCESS DEFINITION

This chapter revisits Sargent's (2001) evolved MPD to focus on the CoM phase and CoM validation of the simulation world. ICoMM presents a generic SE process model to include system architecting in the development of the CoM. A value model is also included to identify SME inputs into the development of the CoM. SME involvement in the development of the CoM is critical early in the MDP, rather than providing expertise at the conclusion of a simulation. The following steps are used in ICoMM to develop the structure of the CoM:

1. Understanding the Operational Concept
    a. Stakeholder Analysis
    b. Requirements Analysis

2. Develop System Architecture
    a. Functional Architecture Development
    b. Physical Architecture Development
    c. Allocated Architecture Development

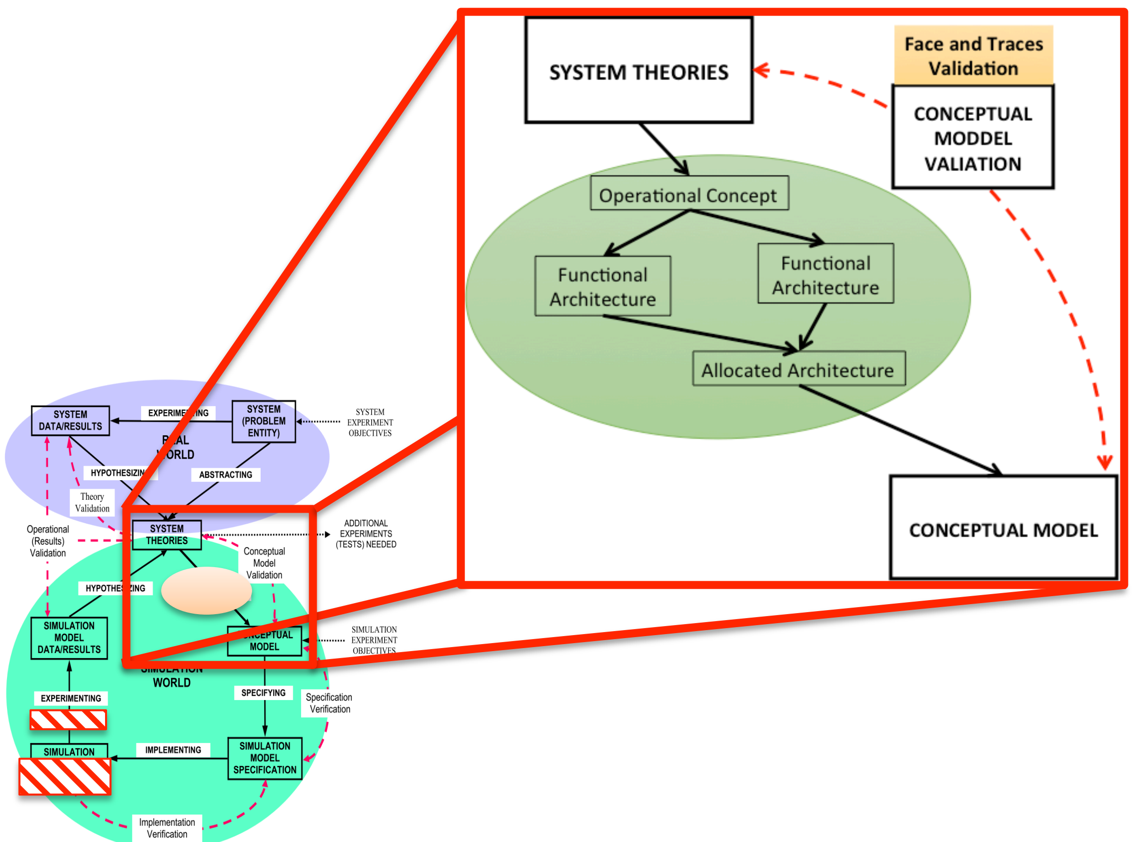
3. Gather SMEs Values
    a. SME Weight of Functions
    b. Impact of the Functions

4. Model Exploration of Non-Observable Systems

Following Sargent's (2001) evolved MDP, we concentrate on the process between systems theories and conceptual model phases. His evolved MDP simply has the term modeling between system theories and conceptual model. ICoMM updates the model to

include Buede's (2009) "Architecture development in the engineering of a system" model by replacing the simple "modeling." ICoMM provides a fills the gap that Turner in his research states is needed to investigate a better transition from system definition to impact variables. Figure 21 shows the "inclusion of architecture development in the engineering of a system" (Buede 2009) as a part of Sargent's evolved MDP. It also identifies the two validation techniques, face and traces, that are used to validate CoMs.

Figure 21. Introduction of Systems Engineering and Systems Architecture in the Model Development Process



Adopted from: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

B. IMPROVEMENT OF THE CONCEPTUAL MODEL

An initial understanding of the system is needed to transition the system from the real world to the simulation world. The real world identifies the need for a system to

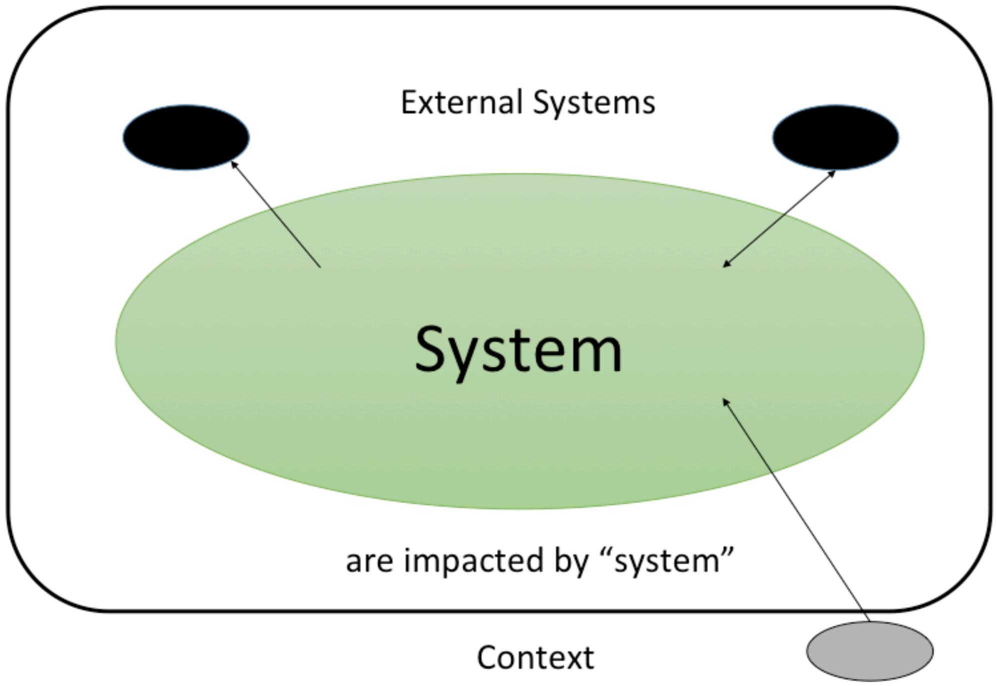
address a deficiency (Blanchard and Fabrycky 2006). ICoMM assumes that the need has been identified and requires a system to be built to address the deficiency. ICoMM facilitates the identified needs of the system from the real world to enter the simulation world to build models of the system to help DMs gain insights and make decisions.

1. Operational Concept

The process begins by establishing an operational concept. A system is created to execute functions to achieve an objective in the real world. The operational concept provides a general picture of the functions, components, and the objectives of the system. It provides a description of the functions and the products produced by the system. It facilitates understanding of the system and the context and its execution as directed by the DM. The operational concept includes scenarios that describe how the system interacts with external systems (Buede 2009). It is a shared idea of the system among all of the stakeholders (Buede 2009). The only outcome of this phase is a shared understanding of the system.

The established operational concept of the system is used by ICoMM to begin developing the CoM. The operational concept establishes the functions and the components of the system, as well as descriptions of the external system and the context in which the system operates. Figure 22 shows the system and its interactions with the external system. The interactions with the external system can be in one direction or both directions. The entity that provides the context for the system is only in one direction. The context scopes and bounds the system's activities during the execution of the system functions. The system cannot affect the entity providing the context. The operational concept defined in this phase is the basis for which to establish the structure of the CoM.

Figure 22. Depiction of the System, External System, and Context



Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 50.

a. Stakeholder Analysis

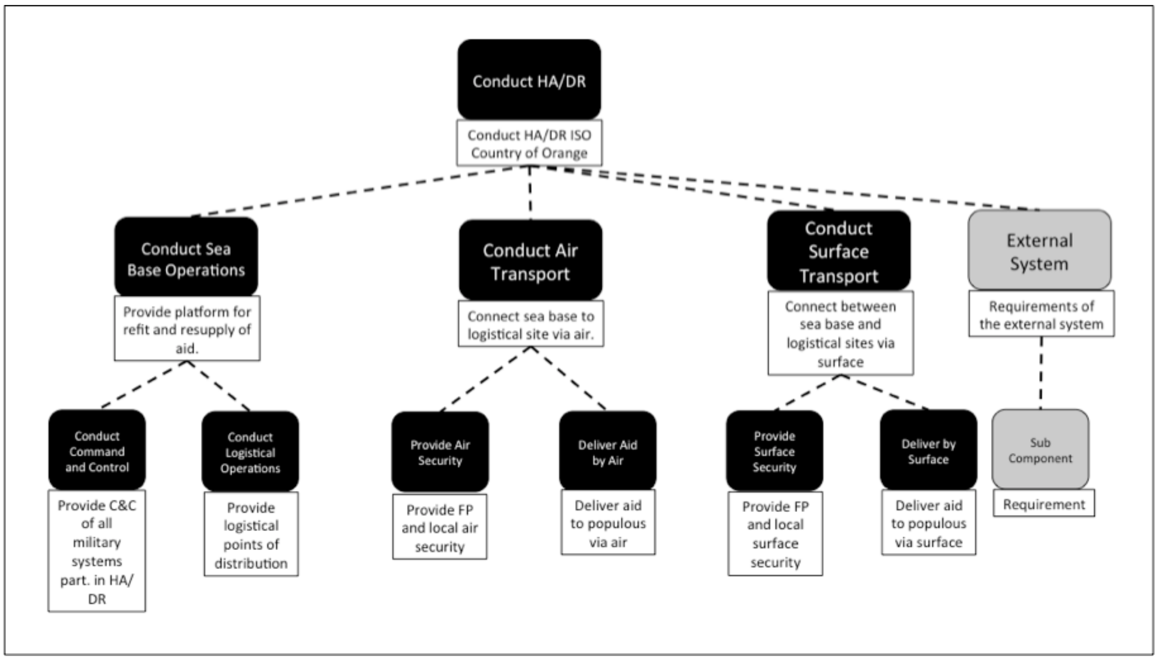
Stakeholder analysis is the initial step in developing the operational concept. This step identifies the objectives, the functions, components, constraints, and values of the DM (Parnell, Driscoll and Henderson 2011). Stakeholder analysis can be conducted in many ways, such as interviews, surveys, and focus groups. This dissertation uses the operational concept established by SE analysis cohort 17, Team A for their master’s thesis.

b. Requirements Analysis

Another aspect of the operational concept is the requirements analysis. Requirements analysis addresses the need and objectives of the system (Buede, 2009). The top requirement is the overall requirement of the system. All the stakeholders support this requirement. This requirement requires the interaction of several subcomponent systems, as well as external systems.

An introduction in this dissertation is that ICoMM also adds the requirements of the external system as part of the requirements analysis. External systems also have requirements that must be met to support the top requirement. Figure 23 shows a depiction of requirements analysis. The external system is identified in a gray box, but shows a linkage between the top requirements and the external system requirement. This is an extension of Figure 21, Buede's (2009) "depiction of system, external system, and context" designing the system to include the external system.

Figure 23. An Example of a Requirements Analysis with External System Requirements



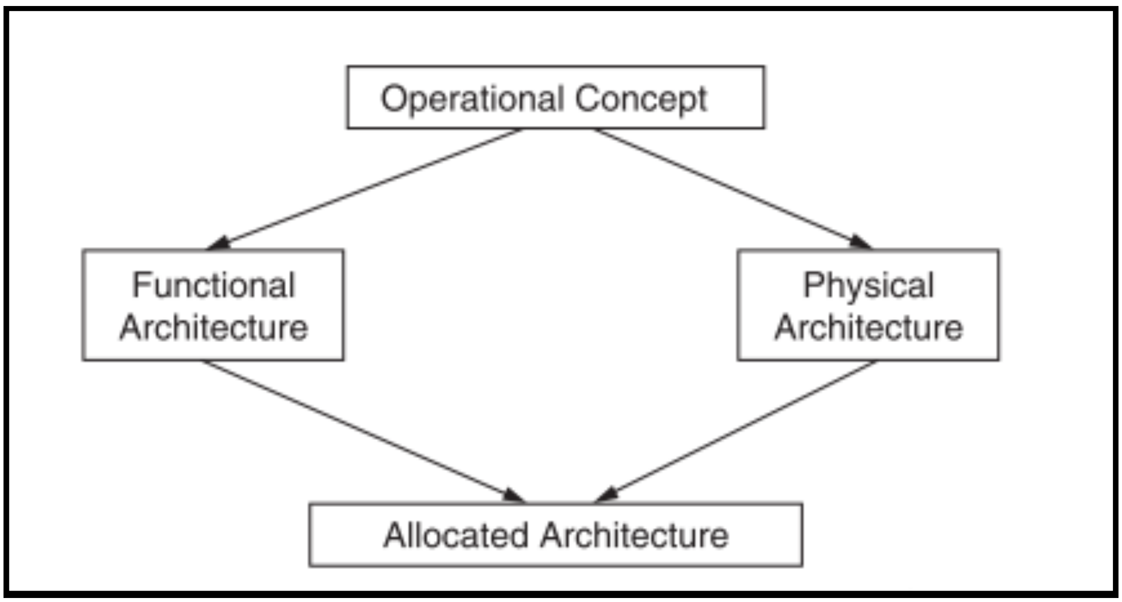
2. System Design

Designing of the system begins once the operational concept has been defined (Buede, 2009). Systems design is the transformation of a system in the stakeholders' minds into models into visual formats (Buede, 2009). ICoMM supports the establishment of the concepts within the minds of the DMs into visible CoMs for simulations. Systems design takes the operational concept presented earlier and conducts decomposition of the functional and physical representations of the system (Buede, 2009). The functional

architecture identifies the functions that must be executed to meet the requirements. The physical architecture identifies the physical components that are part of the system. The allocated architecture identifies the allocation of which physical components will execute the functions to meet the identified requirements (Buede, 2009).

Figure 24 shows how once the operational concept of the system is developed, the decomposition and the integration begin. The functional and physical decomposition of the system is performed by the architecture. Buede (2009) describes "the functional and physical architectures are developed in parallel to provide more meaning when integrated to form an allocated architecture" (27).

Figure 24. Architecture Development in the Engineering of a System



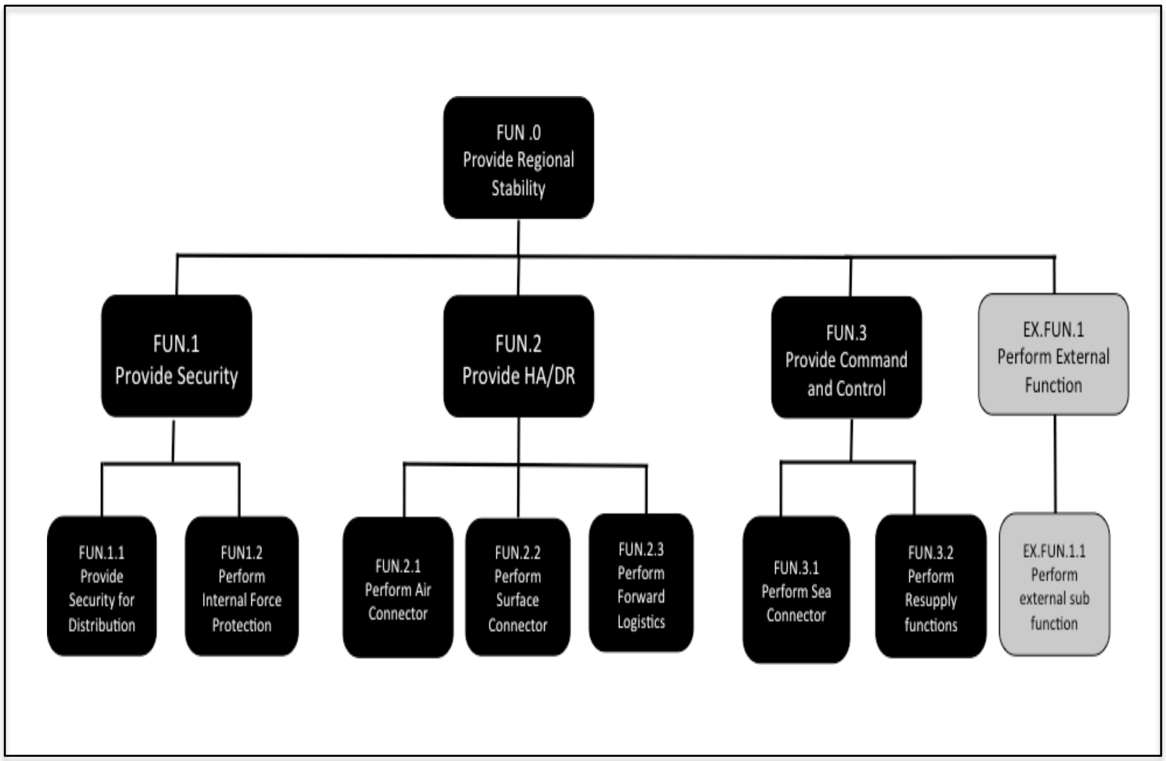
Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 28.

ICoMM integrate the systems architecting process into the MDP to improve the structure of the CoM, as seen in Figure 1. Incorporating systems architecture into the MDP to develop the CoM ensures that the models will more accurately represent the system. In addition, establishing a structured methodology to build the CoM increases the traceability of the model as ICoMM demonstrates in Chapter IV.

a. Functional Architecture

ICoMM uses functional architecture to define what the system must do. The functional architecture is a decomposition of the system's top-level functions (Buede 2009). It identifies the functions that the system is required to execute. A functional hierarchy is created to show the lower-level functions and the link to the top-level function it supports as shown in Figure 25. Once again, ICoMM integrates the functions of the external system to show its relationship to the system. The functions of the external system influence the execution of the top-level function.

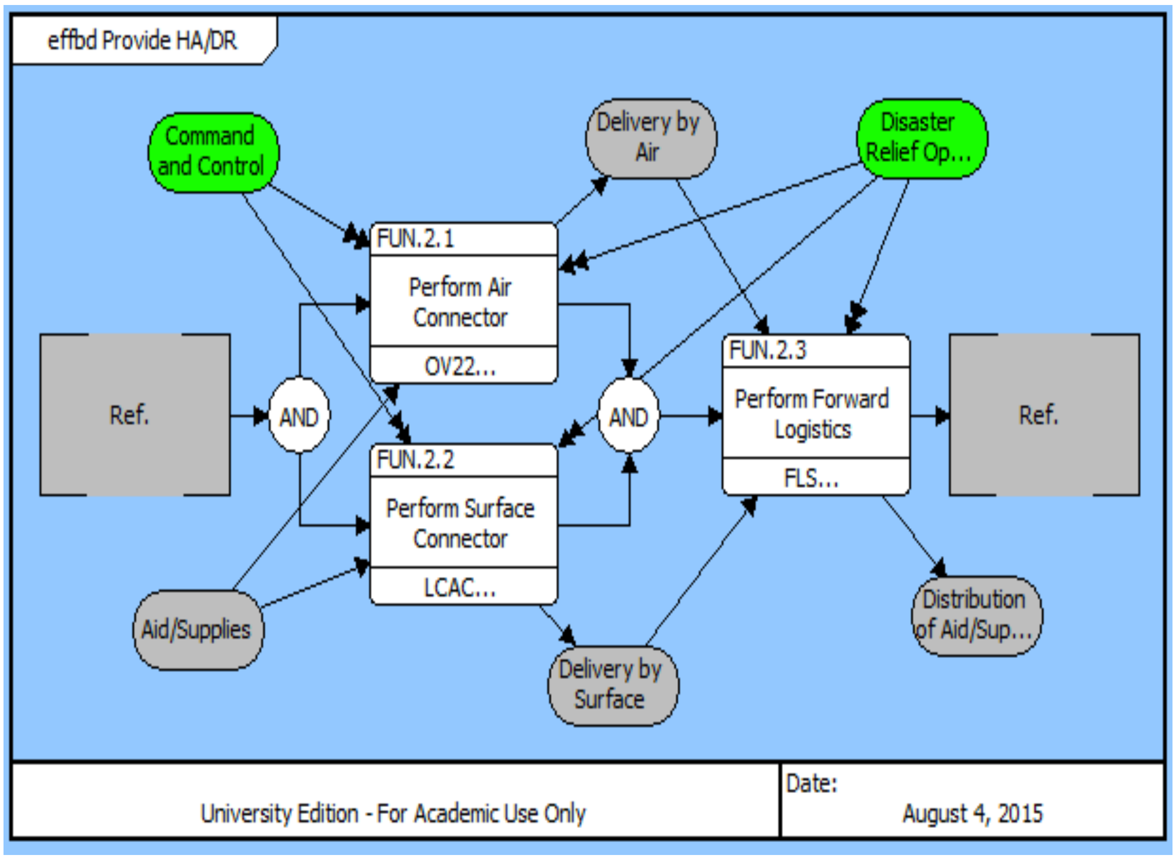
Figure 25. An Example of the Functional Hierarchy



Next, ICoMM identifies the sequence of the function by using the EFFBD as seen in Figure 26. The EFFBD displays the functions and the sequence it is performed. The EFFBD provides dynamic information, which the IDEF0 model cannot display. Figure 25 shows that the two functions, perform air connector and perform surface connector,

can be executed simultaneously, while the perform forward logistics function occurs afterwards because the forward logistics actions of distributing aid cannot be conducted until the aid arrives to the forward logistics sites. The EFFBD is the method ICoMM uses to display this information.

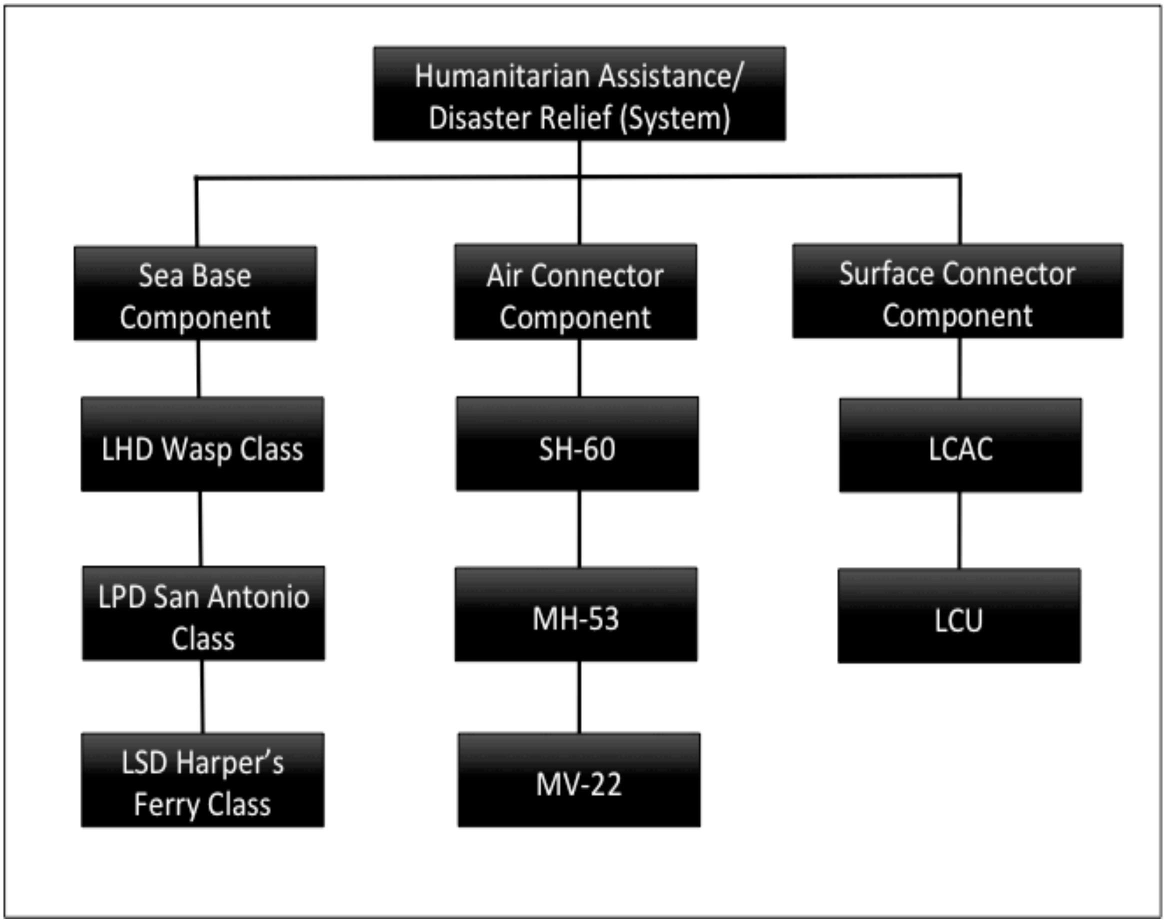
Figure 26. An Example of an EFFBD



b. Physical Architecture

The components of the system are identified following the identification of the functions. The components are the physical aspects of the system that will execute the functions. Figure 27 shows an example of a physical architecture that identifies the components of the system. ICoMM uses a generic physical architecture that defines the physical hierarchy in general terms to understand what components are included in the system.

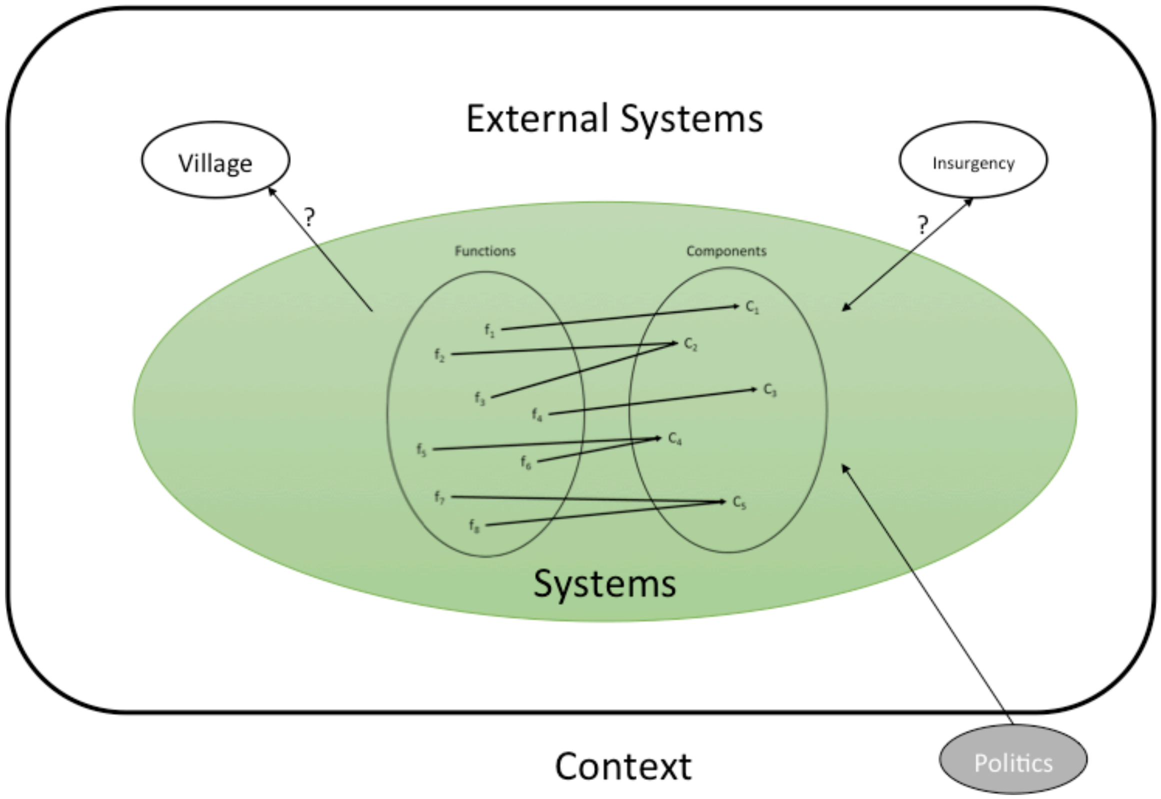
Figure 27. An Example of a Physical Architecture



c. *Allocated Architecture*

The allocated architecture is built after the identification of the functions and the components that will execute the functions. As seen in Figure 28, ICoMM maintains the concept described in Buede's (2009) description of system, external system, and context. Functions and the components are allocated within the system to interact with the external system. ICoMM uses the information about the external system to improve the allocation of the functions to the components. For example, a function of delivering aid would not be necessary for interacting with the insurgency, but provide the necessary security.

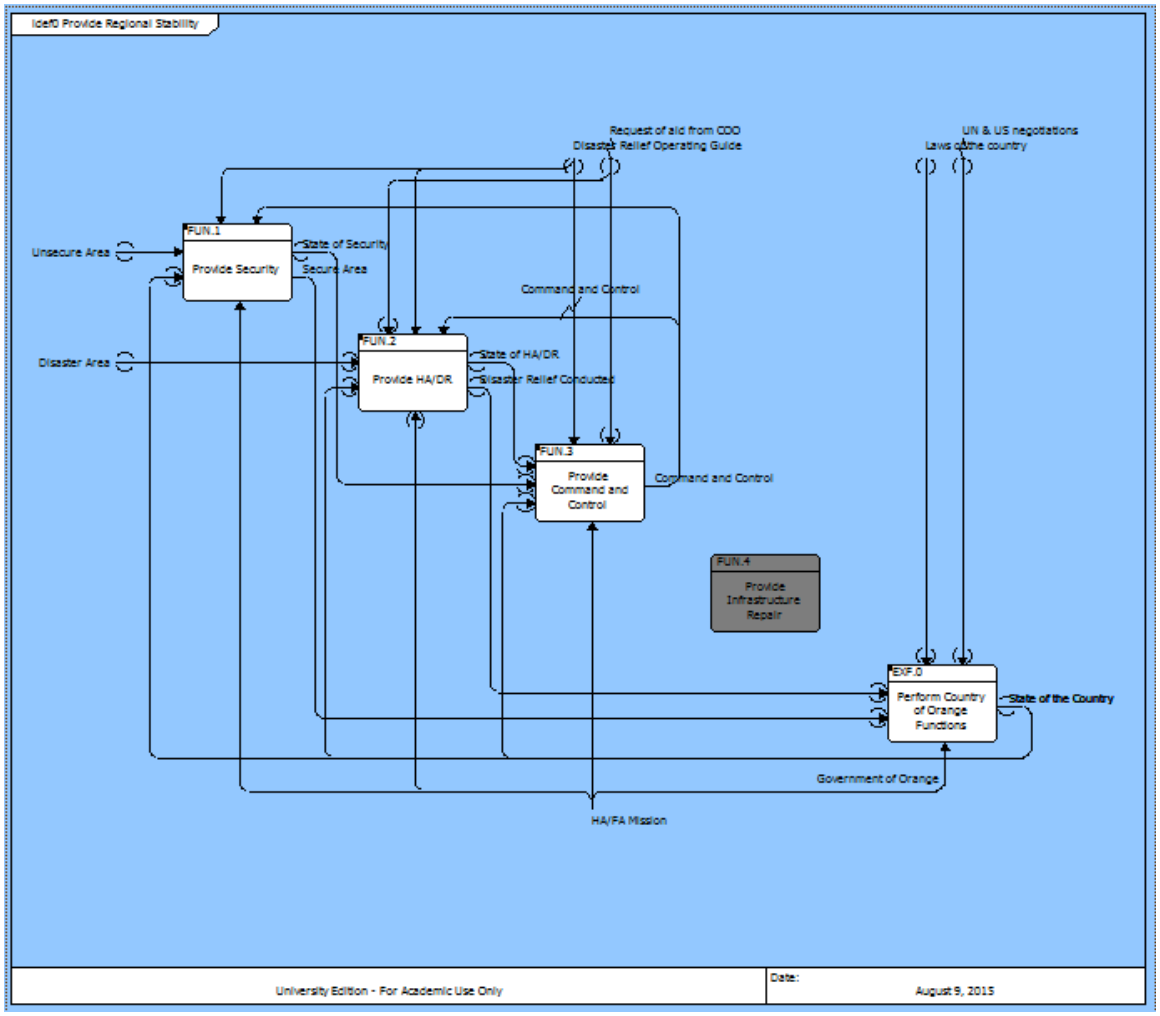
Figure 28. The Allocated Architecture within Designing of a System



Adapted from: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 50.

ICoMM uses the IDEF0 to display the allocated architecture visually. The IDEF0 shows the system design to include the functions as inputs and outputs, the physical components as the mechanism to perform the functions, and the context of the system as the controls. Figure 29 is an example of the IDEF0 model displaying the input and output, the mechanisms, and controls. The allocated architecture provides the structure that allows the traceability from components to functions, and ultimately, to the fundamental objective. The traceability provided ICoMM improves the facilitation of traces validation method of conceptual models.

Figure 29. An Example of an IDEF0 Model

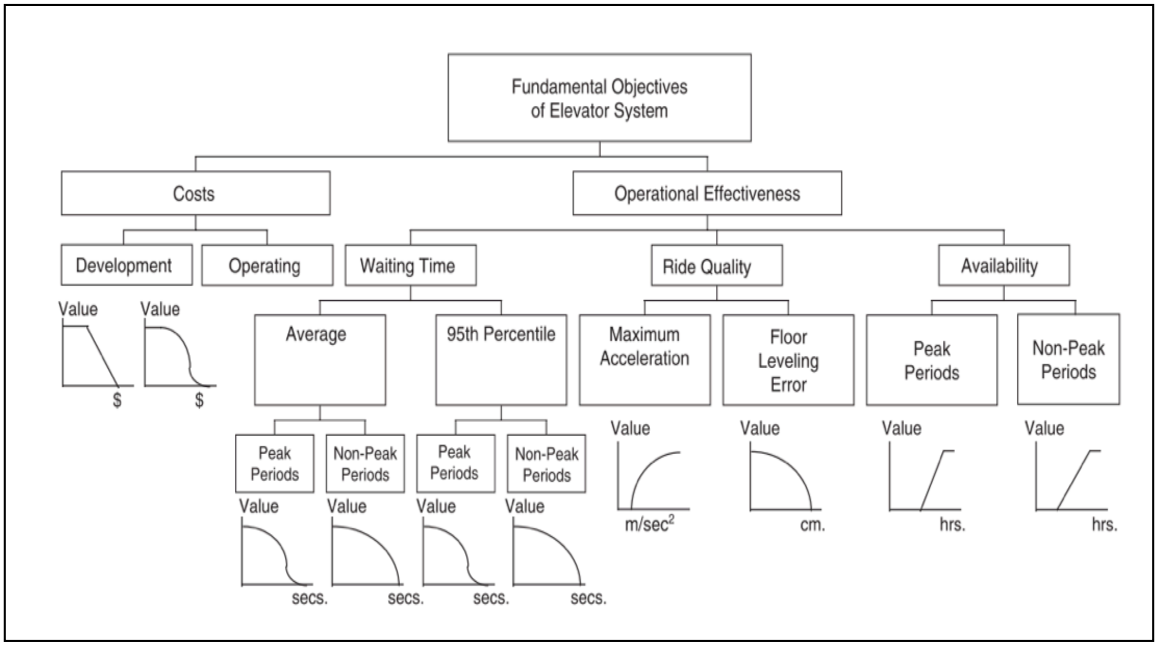


3. Subject Matter Expert Values

Finally, ICoMM includes a value to model to document SMEs' values of functions that will be executed by the system. Traditionally, involvement of SMEs for model validation was at the end of the operational validation. ICoMM ensures that the SMEs provide weights for the functions by their values of importance. These weights are also identified as the impact that the function will have on the output of the system. It is the weights identified by the SMEs that will be evaluated post simulation to conduct operational validation of the NOS. Figure 30 shows an example of how value curves are included in Buede's example of the elevator study. Buede (2009) uses stakeholders to

solicit their values. Although the inputs of the stakeholder values are important, it is the solicitation of SMEs' values of functions of the system that is the basis of ICoMM. ICoMM facilitates face validation of the conceptual model where SMEs are required for validation.

Figure 30. Objective Hierarchy with Value Curves

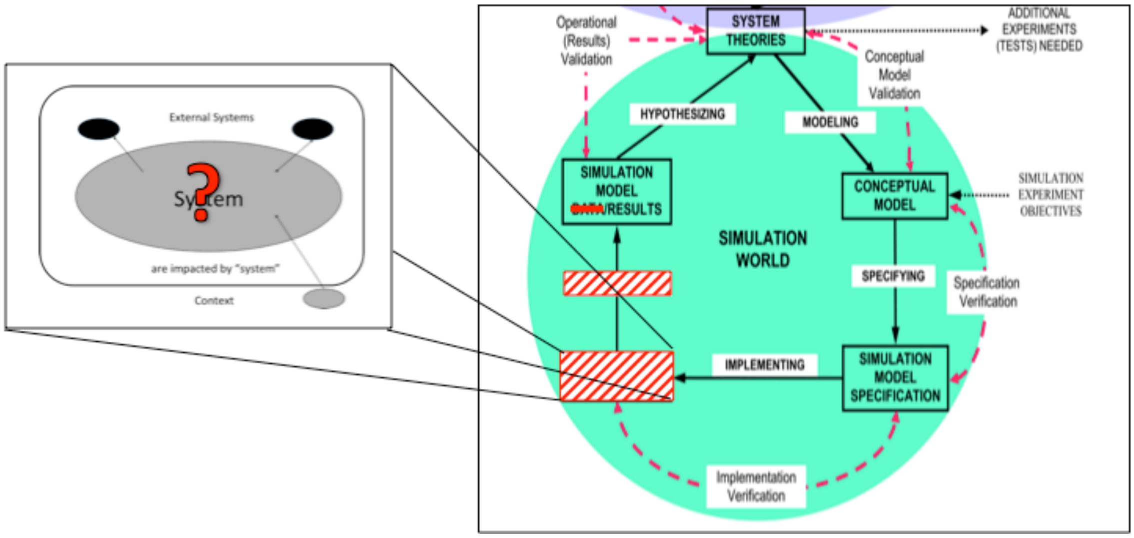


Source: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons. 186.

C. SUPPORTING OPERATIONAL VALIDATION OF NON-OBSERVABLE SYSTEMS

The idea of a CoM is not new. What is novel of ICoMM is the integration of SE methods into the MDP to build CoMs and to improve both conceptual and operational validations. As seen in Figure 31, ICoMM addresses the operational validation needs of systems that meet the criteria to be classified as a NOS.

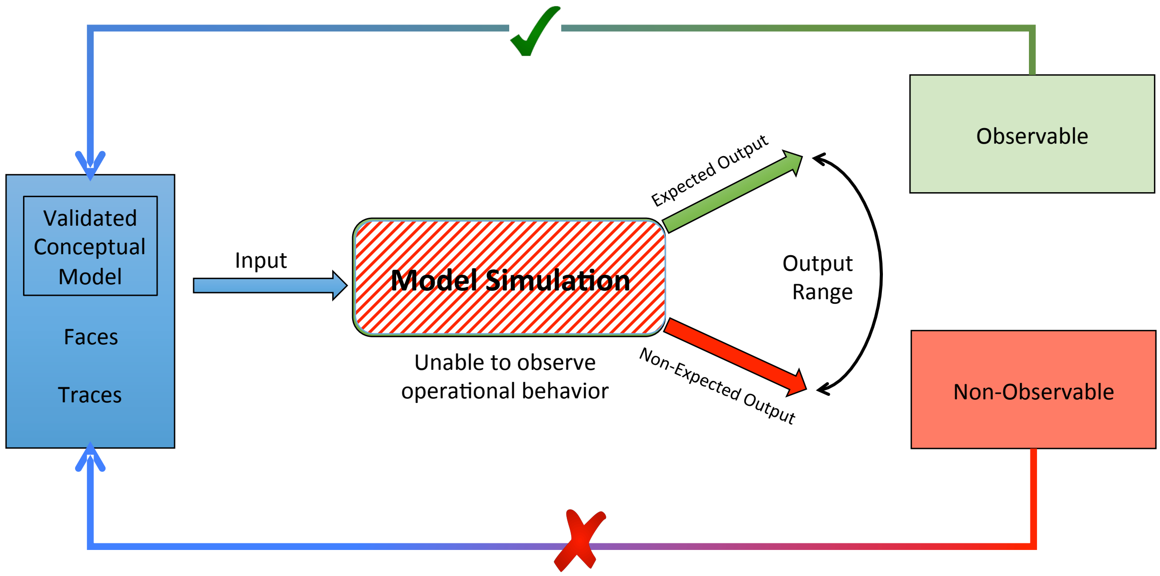
Figure 31. Execution of Simulation of a NOS



Adopted from: Sargent, Robert. 2001. "Some Approaches and Paradigms for Verifying and Validating Simulations Models." *Proceedings of the 2001 Winter Simulation Conference*, 109.

Figure 32 shows the flow of an MDP for a NOS. The only information about the model of the system is the inputs and outputs produced by the simulation. The inputs are allocated functions and components of the CoM. The outputs are the results of the simulation. The outputs may match or deviate from the intended output. If the output matches the intended output, then it is classified as an observable system and the original conceptual model is operationally validated. The model can be presented to the DM to be used for future scenarios. If the output is a deviation of the intended output, then operational validation of the model is infeasible and it is classified as a NOS. The only method to provide an operational validation of a NOS is through model exploration. Thus, the CoM must be reexamined. This methodology is repeated until the output matches the CoM through model exploration. The model of the system is determined to be a failure if the output does not converge to a correct model after multiple iterations. A new system should be designed to address the deficiency. If applied as described in this methodology, ICoMM provides an effective means to conceptually and operationally validate future CoMs throughout the MDP.

Figure 32. Reference Back to the Conceptual Model



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IV. APPLICATION OF THE IMPROVED CONCEPTUAL MODEL METHODOLOGY

To demonstrate the applicability of ICoMM, an analysis of developing a validated CoM of a future DOD HA/DR mission is presented. As mentioned, this dissertation leverages Sargent's (2001) evolved MDP and the inclusion of SE methods into the MDP process to develop ICoMM. It is a continuation of the work of Andrew Turner's "Methodology for the Development of Models for Simulation of Non-observable Systems." Turner (2014) states the need for an improved method for system definition and further research into the proper development of its structure that lacks in his research (330). Systems definition is "the identification of the system of interest and decomposing the system so it can be translated into model formation" (54). The HA/DR mission was chosen based on two criteria. First, the scenario is based on missions DOD will execute in the future. HA/DR missions are dynamic and each mission is different. Although similar HA/DR missions may have been executed, future interactions between external systems and the context in which the system operates in will differ. Second, the scenario facilitates the comparison of ICoMM to previous research conducted by Andrew Turner. This dissertation presents ICoMM as a way to improve both systems' definition and structure of the model to demonstrate its contribution. ICoMM furthers the research by strengthening the validation of the CoM and its support to operational validation of a NOS. This dissertation is not intended to be a criticism of the previous research, but rather the acknowledgement of the novel concept of modeling a NOS and addressing a necessary expansion to validate models of a NOS. It is the intent of this dissertation to use ICoMM to develop models of systems that are trusted by DMs to make critical decisions.

This chapter applies ICoMM to a scenario that requires a CoM to be developed and validated and to be executed in a simulation. The CoM is developed with SME input and improved structure to be traceable for model exploration after the execution of a simulation. The identification of system need is already established in the scenario. ICoMM is applied from the operational concept to conduct system definition and

decompose the system to build the functional, physical, and allocated architectures. Finally, ICoMM define the impact of each of the functions of the system with the value model.

A. HUMANITARIAN ASSISTANCE / DISASTER RELIEF SCENARIO SELECTION

This dissertation investigates a HA/DR scenario to compare previous research of modeling of NOSs by Turner. The scenario is based on a master's thesis by the Naval Postgraduate School, Systems Engineering Cohort 17 in 2011 about the influence of foreign HA/DR in a coastal nation (Alexander et al. 2011). Again, this scenario was chosen because this research is a continuation of Turner's research.

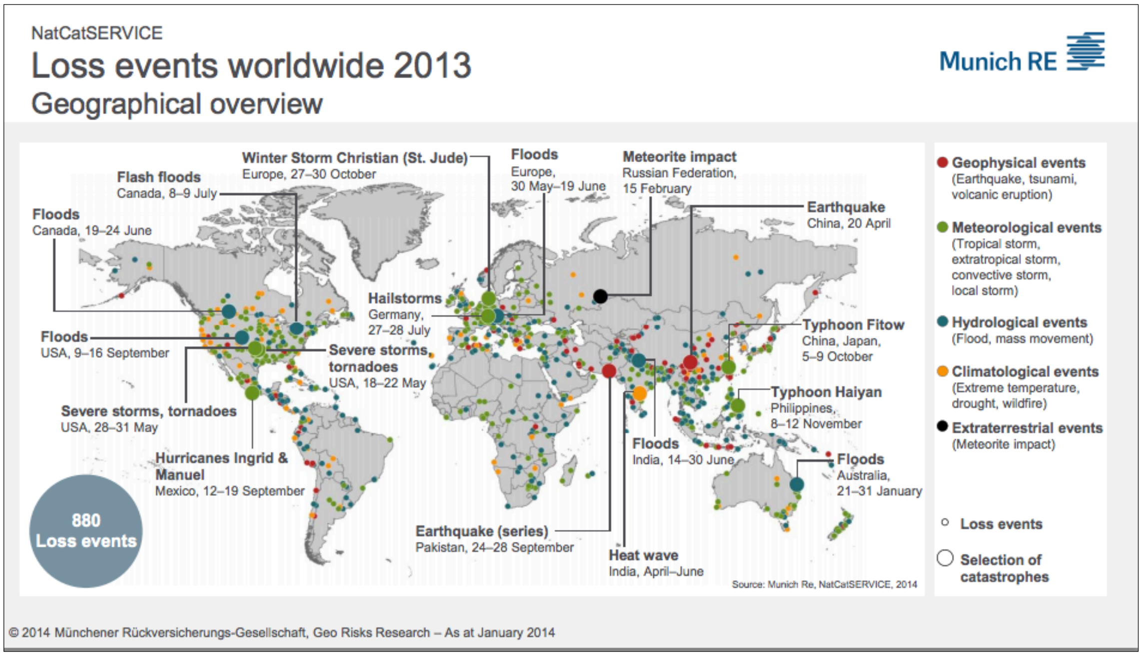
The HA/DR scenario meets the definition of NOSs defined earlier as non-ability to observe the behavior of the interaction of two systems and the result is the deviation of actual effects from the intended effects. The data of the interaction between the system and the external systems cannot be directly collected during the execution of this scenario. The operational validation of this model is infeasible for this scenario due to its classification as a model of a NOS. Thus, the operational validation is conducted by model exploration of the CoM and face validation methods relying on SMEs.

The scenario is set in the future in a conceptual environment with very little information of the population and their social issues. The military system conducting the HA/DR effort includes components, such as the T-Craft, a high-speed/high-volume cargo carrier not part of the current U.S. Naval fleet. The success of the operation depends on the satisfaction of the population receiving the aid and the reduction of the population into criminal behavior (Alexander et al. 2011). These two success criteria are based on the interaction between the military system and the local populous.

HA/DR is one of the very important missions that the U.S. military has been participating in for many years. In 2013, the United Nations reported 880-loss events worldwide (Munich RE 2014). A graphic depiction is seen in Figure 33. The United States has been the largest provider of humanitarian assistance by contributing $4.7 billion worldwide. The largest recipients of U.S. assistance have been sub-Saharan

countries in Africa. For the past decade, sub-Saharan countries received 59% of overall U.S. aid (Global Humanitarian Assistance 2013).

Figure 33. Loss Worldwide Event 2013



Source: NatCalSERVICE. 2013. "Loss Events Worldwide, 2013 Graphical Overview." https://www.munichre.com/site/mram/get/documents_E-725556400/mram/assetpool.mr_america/PDFs/5_Press_News/Press/natcat012014/2013_worldmap_events.pdf.

Alexander et al. (2001) also states that the group's reason for selection of this scenario is that OPNAV N8F directed a study into the designing of systems architecture to support a HA/DR mission for a developing nation. The design team was requested to design and assess a system that provides continual, multi-year support for a host nation's efforts to ensure security and stability during a HA/DA mission. The primary goal was to develop a "regional stability systems architecture." This system would consist of a sea base and sea base connectors with the following capabilities:

- Disrupt social interruption activities and provide humanitarian aid through the use of joint and coalition naval forces
- Address potential local population support for disruptive forces

- Address the reasons for enemy forces to engage in disruptive activities (Office of the Chief of Naval Research 2011)

The concept of the HA/DR mission is based on Expeditionary Warrior 10 (EW10) wargame scenario developed at the USMC Wargaming Division. The overarching questions to answer are, "how well is aid being distributed to the population and the effect of HA/DR on the population" (United States Marine Corps Wargaming Division, Marine Corps Warfighting Laboratory 2010). ICoMM builds a conceptual model to address the questions posed by OPNAV N8F and the USMC Wargaming Division by identifying the functions of the system, the external system, and their interactions.

B. SCENARIO OVERVIEW

The HA/DR scenario presented by Alexander et al. (2011) is set in 2022. A devastating storm greatly damaged the western African region with great destruction and heavy flooding. The Country of Orange (COO), at the limits of its internal emergency resources, requested foreign assistance to the United Nations (UN). The United States, which is a member nation of the UN, responded to the request for assistance. The DOD was tasked to provide immediate support to the disaster region by sending a Naval expeditionary strike group (ESG) composed of a Marine expeditionary unit (MEU) capable of conducting HA/DR missions. ICoMM is applied to this scenario to improve the structure of the CoM by including the external system and context to the architectures.

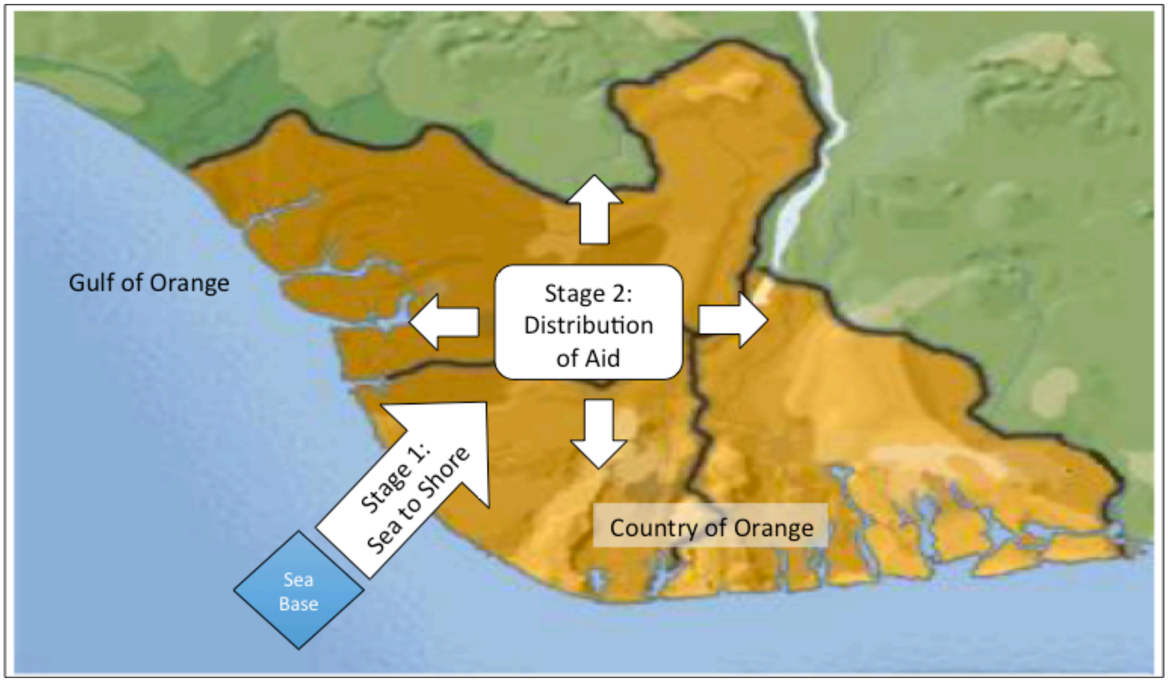
C. OPERATIONAL CONCEPT DEVELOPMENT

A review of the operational concept for the HA/DR scenario is conducted to identify the system, external system, and potential interactions. The operational concept defines how the military systems will be used to interact with local systems during the HA/DR operation.

The U.S. military, with support from other-government organizations (OGOs), such as the State Department's United States Agency for International Assistance (USAID) and non-government organizations (NGOs), are called to provide aid to the people of Orange. The main effort of the HA/DR mission will be from the sea due to

heavy damages to Orange's infrastructure. An off shore sea base will start the two stage relief effort. In the initial stage, aid will be transported from a sea base to a forward logistics site (FLS) and to the forward logistics satellite site (FLSS). The second stage is to deliver the aid from the FLSS to the local populous. Figure 34 shows the flow of the operation and an overview of the mission.

Figure 34. Operational Overview of the HA/DR Mission

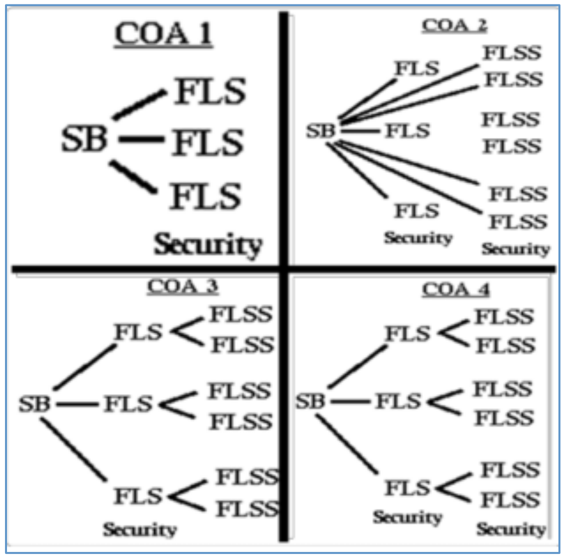


Source: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 7.

Four courses of action (COAs) were presented for the delivery of aid. The courses of actions differ on the matter of who will directly deliver the aid to the local populous. In the first COA, the military delivered aid material to the FLS only and the non-military organizations would provide delivery to the FLSS, and subsequently, to the populous. For COA 2, the military would deliver to all the FLSs and the FLSSs. This COA would use more military resources; however, but would ensure that security was provided to the people. For COAs 3 and 4, the delivery of aid would be conducted in stages to the FLS

first and then to the FLSS. The difference between COAs 3 and 4 is that local security would not be present at the FLSS in COA 3. Figure 35 displays the different COAs.

Figure 35. Four Courses of Action Overview

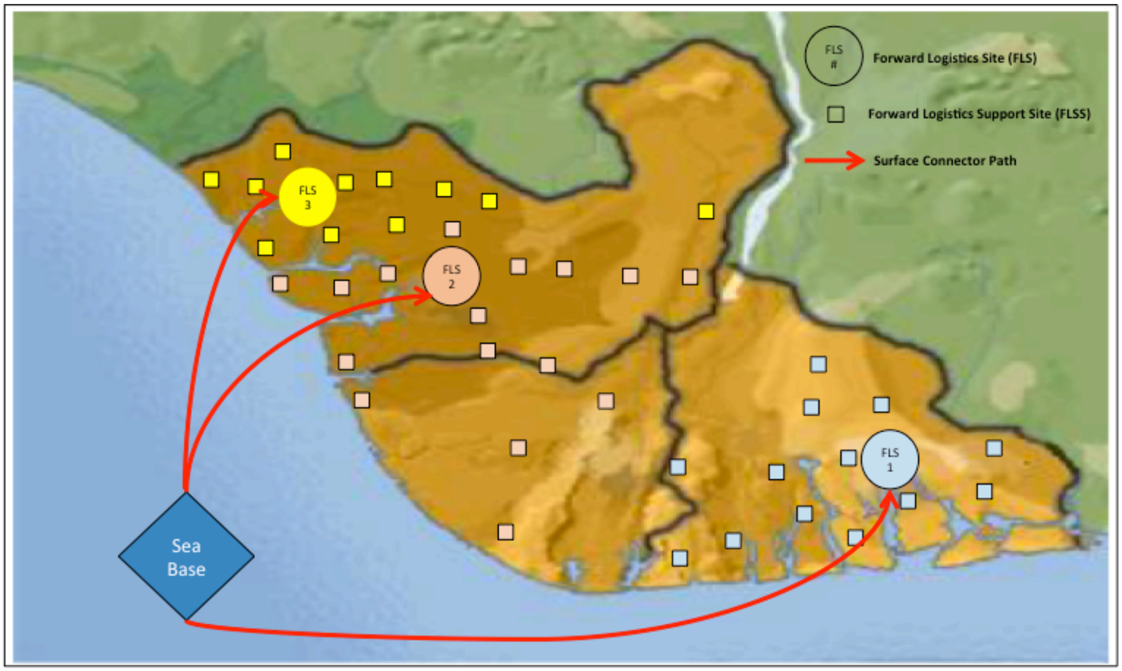


Source: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, xxxvi.

1. Course of Action Decision

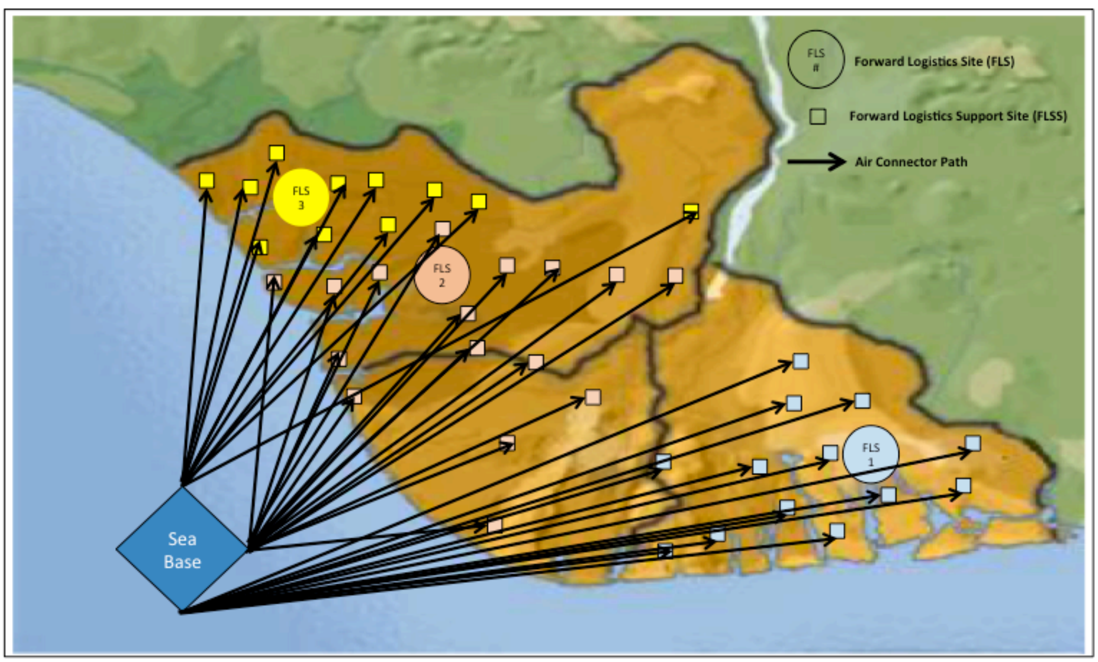
COA 2 is selected for the proof of concept following the work of Turner's (2014) research to demonstrate the modeling NOSs for simulations. Modeling of the other COAs requires a model for each of the COAs, which is redundant and time consuming. Another reason for COA 2 selection is that the SE Cohort 17 in their capstone project demonstrated that COA 2 was the optimal COA for their research. COA 2 is used to build the system architecture to demonstrate its traceability. COA 2 is also simplest in concept. All the platforms directly deliver aid to the FLS and the FLSS with security. The air connectors deliver aid to the FLSS located in remote locations away from access to the sea. The surface connectors deliver to the FLS, which are closer to access from the sea. Figure 36 shows the path the surface connectors use and Figure 37 shows the air connector path to deliver aid.

Figure 36. Surface Connector Path to the FLS



Source: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 55.

Figure 37. Air Connector Path to the FLSS



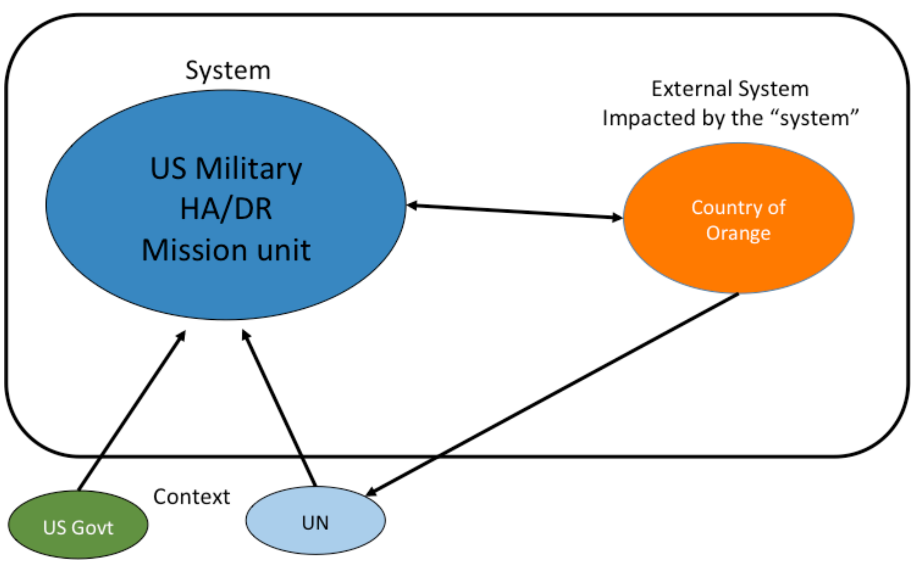
Source: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 57.

The flight paths of the air connectors vary based on the number of platforms and the consumption of fuel to travel to the FLSS. The flight paths and the course the sea connectors take to the logistic sites were not calculated because it is not in the scope of this research. This research does not address the optimal travel paths or network analysis.

2. Identification of Systems

The first step in ICoMM is to identify the systems involved in the scenario. Figure 38 provides a picture of the identified system, external system, the context in which they operate and the relationships between them. The two main systems in this scenario are the actual system that we know and the external system that the system will be impacting. The U.S. military HA/DR unit is the system with available data and the DM has the ability to change its composition or COA. These decisions are based on the impact the system has on the external system. The external system in this scenario is the COO. The HA/DR mission unit conducts HA/DR operations in the COO and must determine if its actions are achieving the intended effects as envisioned by the DM. The double-headed arrow between the two systems is used to show that the actions of both systems may influence each other.

Figure 38. Systems Relationship Diagram

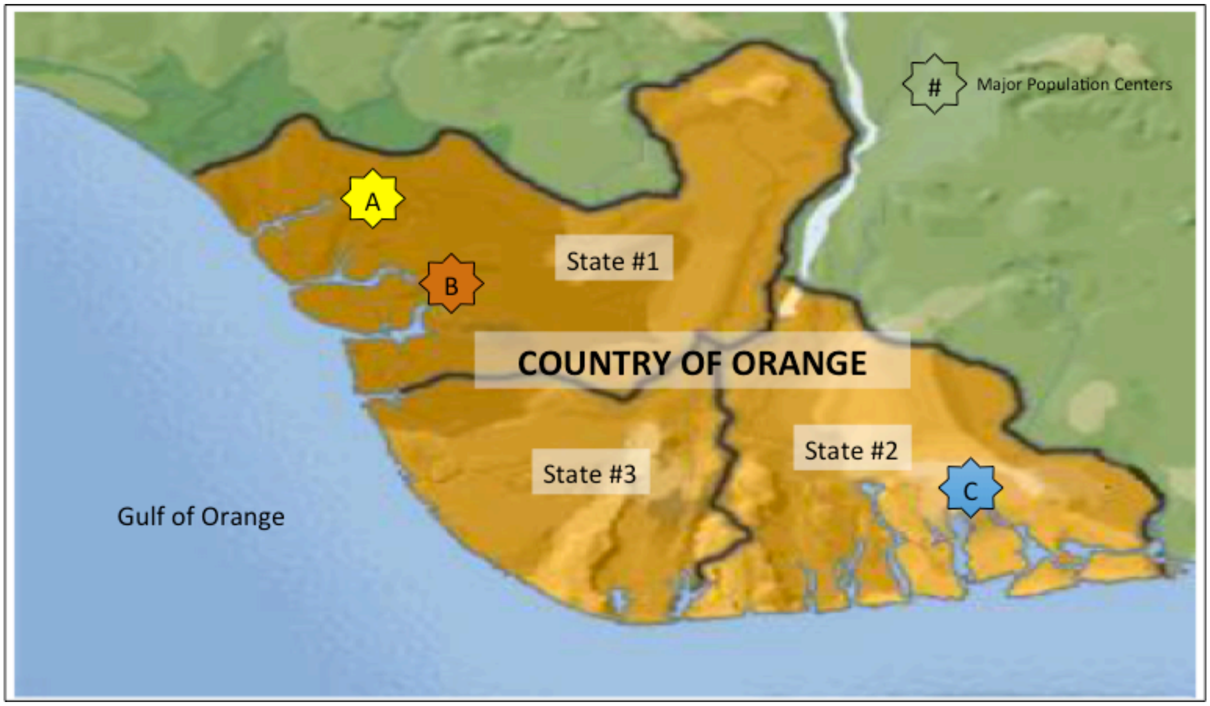


Adapted from: Buede, Dennis. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley & Sons, 50.

a. The Country of Orange

Orange is an African nation strategically situated next to the Gulf of Orange on the west. Figure 39 shows the three major population centers of the country of Orange. Two major population centers are in state number one and one population center in State number two. All three major population centers can access the Gulf of Orange.

Figure 39. The Geography of Orange



Adapted: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 4.

Orange politically has many internal problems. It is a diverse country with a population of 179 million divided into 250 different ethnic groups. The majority of the population is divided into 70 million Muslims in the north and 70 million Christians in the south. In the north, radical Islamic groups, such as Al Qaeda in Islamic Maghreb (AQIM), is very active, while a growing number of participants in the Movement for the Emancipation of Southern States insurgency in the south threaten the stability of Orange.

The storm has had devastating impact on the population of Orange. Table 3 shows the breakdown of the population and the effects of the devastating storm. The storm had the most effect on the two western states of 1 and 3. State #2 in the eastern most region was least affected. However, State #2 also host hostile feelings towards the GOO and may conduct anti-government activities to influence the populous to turn against the Government of Orange (GOO).

Table 3. Breakdown of the Population and the Effects of the Storm

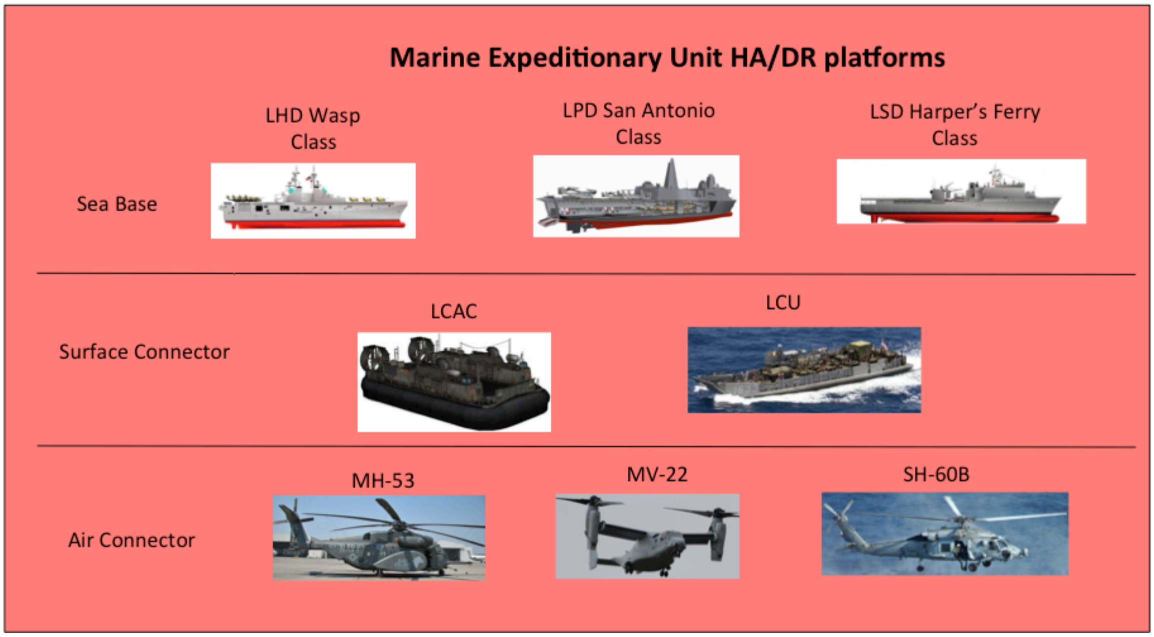
State	Population (mil)	# Dead	# Injured	# Diseased	# Displaced	Total Affected	Attitudues toward mission
1	4.1	85	750	2000	97,000	243,000	Neutral
2	1.7	5	150	300	17,000	25,000	Hostile
3	5.2	35	350	600	19,600	34,000	Neutral
Total	11	125	1250	2900	133,600	302,000	

b. The Humanitarian Assistance/Disaster Relief Mission Unit

The DOD directed a Naval ESG to execute the HA/DR mission in support of the COO. The ESG sent a MEU to begin an initial push into the COO with its forces and capabilities. The MEU provides important capabilities that will be needed to execute the mission. The MEU is comprised of 2,200 Marines and has the capabilities to provide air connection and surface connection, as well as internal security. The sea base conducts command and control (C&C) of the mission.

The sea base is comprised of three amphibious ships: A Wasp class Landing Helicopter Deck (LHD), a San Antonio class Landing Platform Dock (LPD), and a Dock Landing Ship (LSD). The LHD, being the largest of the three ships, will provide the overall C&C. All three ships carry vehicles with a capability to connect to the FLS and the FLSS. The air connector duties will be conducted by three different aircrafts: MH 53, Sea Stallion, MV-22 Osprey, and the SH-60B, Sea Hawk. The surface connection will be performed by two platforms, the Landing Craft Air Cushion (LCAC) and the Landing Craft Utility (LCU). Figure 40 shows the different platforms that will be executing the HA/DR missions. The specifications of all the platforms are listed in Appendix B.

Figure 40. MEU Vehicles Participating in the HA/DR Mission



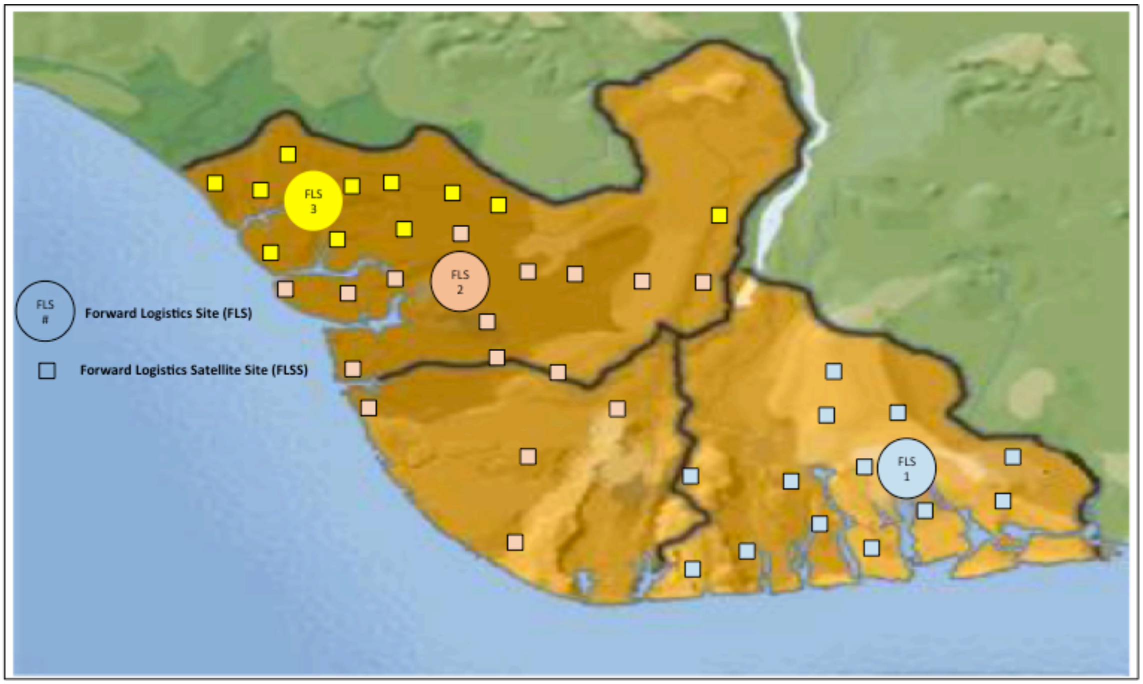
Adapted from: Alexander et al. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 44.

A forward logistical site also supports the HA/DR mission for the DOD. The Joint Staff publication 3-35 defines the Naval FLS as the following:

> An overseas location, with port and airfield facilities nearby, which provides logistic support to naval forces within the theater of operations during major contingency and wartime periods. (JP 3-35 2013, GL–7)

The HA/DR mission to support the COO establishes two types of logistics sites, a FLS and a FLSS to support the distribution of aid to the local populous. The FLS and the FLSS work with government and non-government agencies to deliver and distribute aid to those who cannot travel to the logistic sites. The FLS is the larger of the two types and is established near three major population centers of A, B and C and near watercraft entry points. There are no FLS in State #3 due to the lack of a major population center. The location of the FLSS is also based on the distribution of the population throughout the country. There are 41 FLSSs to support the HA/DR mission. Figure 41 depicts the locations of the FLS and the FLSS.

Figure 41. Locations of the FLS and the FLSS



Adapted: Alexander et al. (2011). "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." Master's thesis, Naval Postgraduate School, 53.

3. Stakeholder Analysis

The Unites States and the United Nations have a strategic goal of maintaining stability in the region. A lack of response to the disaster may provide a catalyst for the increase of hostile sentiment towards the GOO by the local populous. The anti-government forces have the potential to increase hostile activities by instigating the emotional vulnerabilities of the people. The U.S. government and the United Nations provide the context of the operation. The context impacts the system, but the system does not impact the context. The Unites States and the United Nations control the behavior of the system by issuing strategic guidance, setting rules of engagement, and relaying request from the GOO. They can also set strategic requirements for the system.

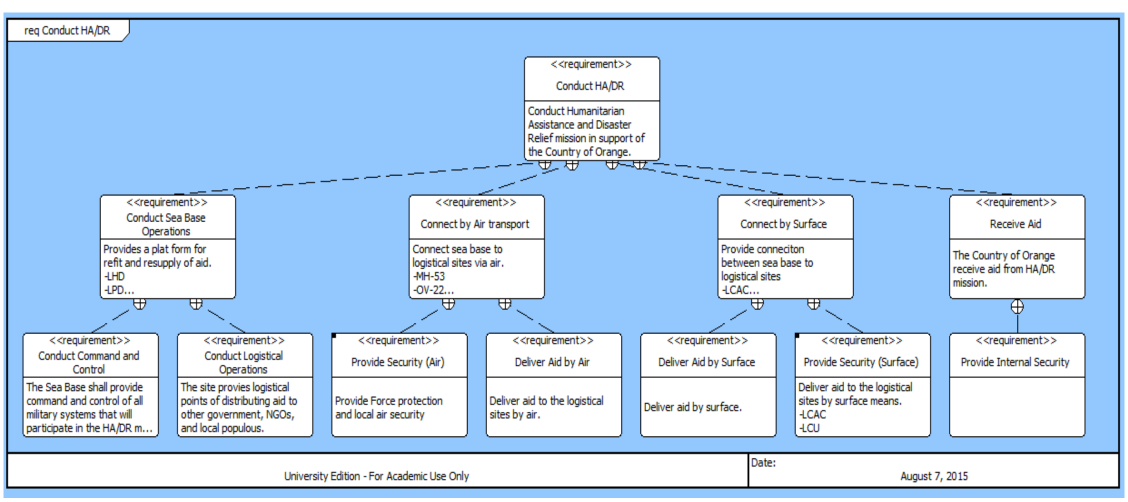
Referring back to Figure 38, the diagram provides a general idea of the over concept of the mission. It is important to understand the arrow with the two heads because it signifies the interaction between the system and the external system, and not

just the impact. The identification of which functions are performed by specific components and how the system interacts with the external system are conducted during the building of the allocation architecture. The interaction between the two systems is non-observable and operational validation is infeasible. ICoMM is used to facilitate model exploration to support the operational validation of this scenario.

4. Requirements Analysis

ICoMM identifies the requirements for conducting the HA/DR mission from the operational concept. The requirements products identify the needs of the stakeholders of the mission. The stakeholders are anyone who has an interest in the decision to participate in HA/DR, execute the mission, and receive aid from the mission. Three levels of requirements are identified for this mission. Figure 42 shows the requirements hierarchy of the mission. The top level is the primary requirement for the system is to conduct HA/DR mission. It is important to all the stakeholders that the HA/DR mission is conducted. The HA/DR requirement provides the overall requirement of the mission. All the components of the system will be in support of conducting the HA/DR mission. ICoMM's contribution to the requirements hierarchy is the addition of the external system's requirements. It is important to identify the external system's requirements because it has a direct or an indirect relationship to support the top-level requirement.

Figure 42. Requirements Hierarchy for the HA/DR Missions



The HA/DR requirement is supported by four supporting requirements in the next level. These supporting requirements are needed to achieve the primary requirement. These requirements are to conduct sea base operations, air transport, connect by surface, and receive aid. The first three requirements are the needs of the HA/DR mission system while the last requirement is the need of the external system. The layout of the requirements is designed to show not only the requirement of the system, but the external system as well. It provides the stakeholders a graphic display of how the needs of both systems support the primary requirement of conducting the HA/DR mission. The lowest level of requirements identified in the system is to support the second level requirements.

The requirements of conducting C&C and logistical operations are under the requirement of conducting sea base operations. These requirements were identified to ensure that the overall functions of the mission had oversight and resupply was conducted to continue the operations for a 15 or an extended 60-day mission. C&C is a subtask of conducting sea base operations. It is responsible for overseeing the entire HA/DR mission. The other level two requirements do have the responsibility of this requirement. The sea base is also the point for resupplying the units participating in the mission.

There are two requirements to deliver aid to the FLS and the FLSS. First, conducing air transport requirement is needed to reach the FLSS that cannot be reached by either the sea or surface connectors. The requirements that support the air connector requirements are to provide air security for force protection (FP) and delivery of aid to the logistical sites. The surface connectors' requirements are to deliver aid to the FLS where it is closer to the water inlets. The surface connectors' requirements are to provide security and delivering aid.

The last level 2 requirement is to receive aid. This is a requirement for the COO. The people of Orange must be able to receive aid for the mission to be successful. There is also a level 3 requirement to provide internal security against the anti-government forces.

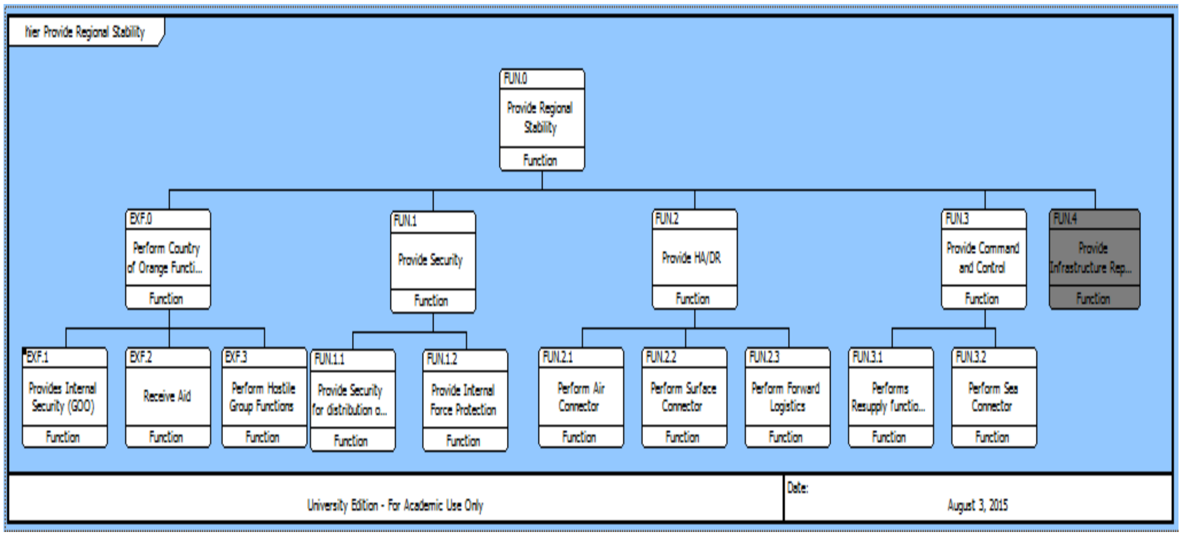
D. SYSTEM ARCHITECTURE

The decomposition of the system occurs during the architecting phase. The three types of architecting, functional, physical, and allocated, are discussed in the following sections. Functional architecture is created to facilitate the identification of the attributes of the systems. Physical architecture is created to identify all the components of the systems. An allocated architecture matches the functions to components. Finally, a value model is built to identify the functions that SMEs value having the most impact during the interaction between systems. Turner (2014) addresses these functions as "impact variables" in his research. Again, this research fills the gaps Turner identified in his previous work by improving the identification of system definition and the structure of conceptual models of NOSs for validation.

1. Functional Architecture

The functional analysis begins once the requirements have been identified. It is through the functions that the requirements for the systems are met. Figure 43 shows the functional hierarch of the HA/DR system. The initial functions are derived from the Joint Tactics, Techniques, and Procedures for Humanitarian Assistance doctrine (Department of Defense 2001). ICoMM identifies that sub-level functions not mentioned in the joint publication. ICoMM also tailored the functional architecture in Figure 42 to include the functions of the external system, as well as the system, but exclude the function that is outside of the scope of the HA/DR mission. This deviation from the joint doctrine supports the concept of this dissertation of including the external system and the context in the design of the system.

Figure 43. Functional Hierarchy



The overall function of the entire system is to provide regional stability. Regional stability is maintained by the next level 2 functions. They provide security, HA/DR, C&C and infrastructure repair. Infrastructure repair is blackened because it will not be a part of this scenario. No HA/DR mission assets are dedicated for infrastructure repair. The external system function of perform Country Orange functions is included because it supports providing regional stability.

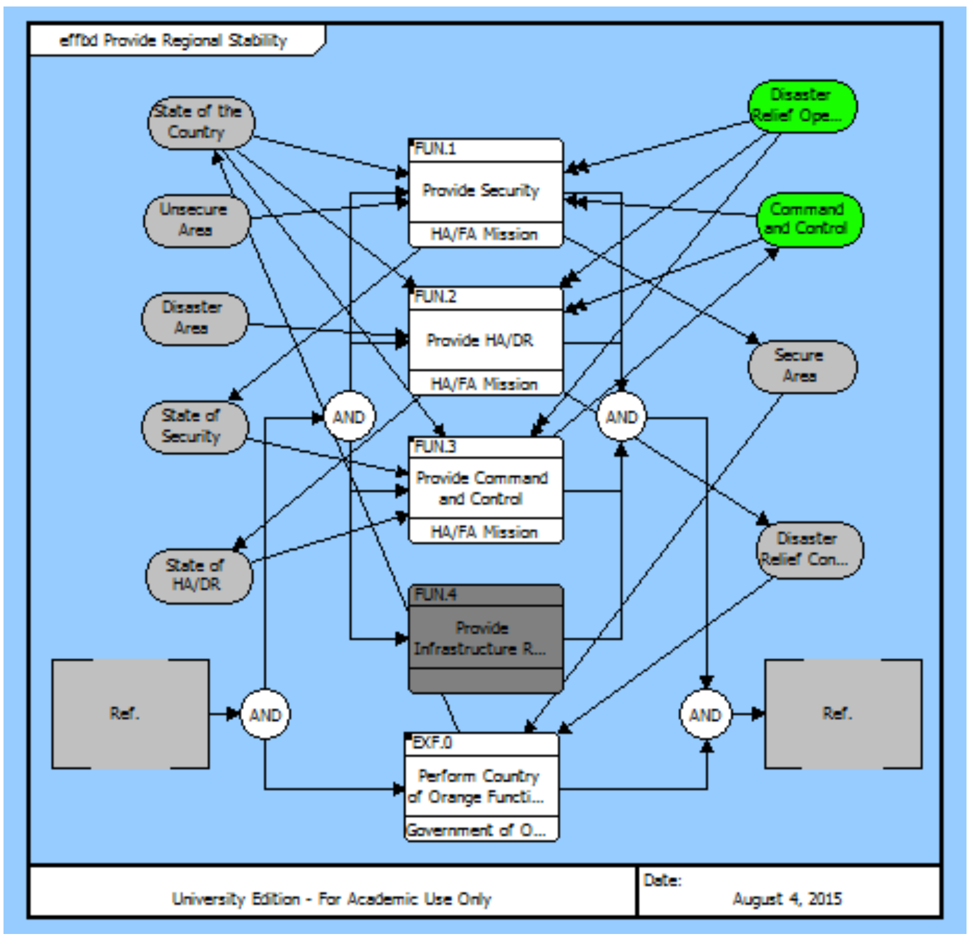
2. Enhanced Functional Flow Diagrams

As described in Chapter II, the EFFD provides another view of the functions compared to the functional hierarchy. It shows the sequence of the functions that must be executed. The sequence of the functions is important to ICoMM because it is another tool for model exploration should the NOS deviate from the intended output. The following diagrams show the EFFD for the sequence of functions for the top and lower level functions as examples.

a. Provide Regional Stability

Figure 44 shows an EFFD to provide regional security to illustrate that the lower level functions are conducted simultaneously as noted by the word AND in a white circle. However, the external system's function is depicted on separate parallel line. The external system's functions will be performed simultaneously, but not as part of the system. It will support the overall function of maintaining regional stability, but not as a part of the system. Again, the provide infrastructure function is blackened because it is out of the context of this mission.

Figure 44. Provide Regional Stability Functions

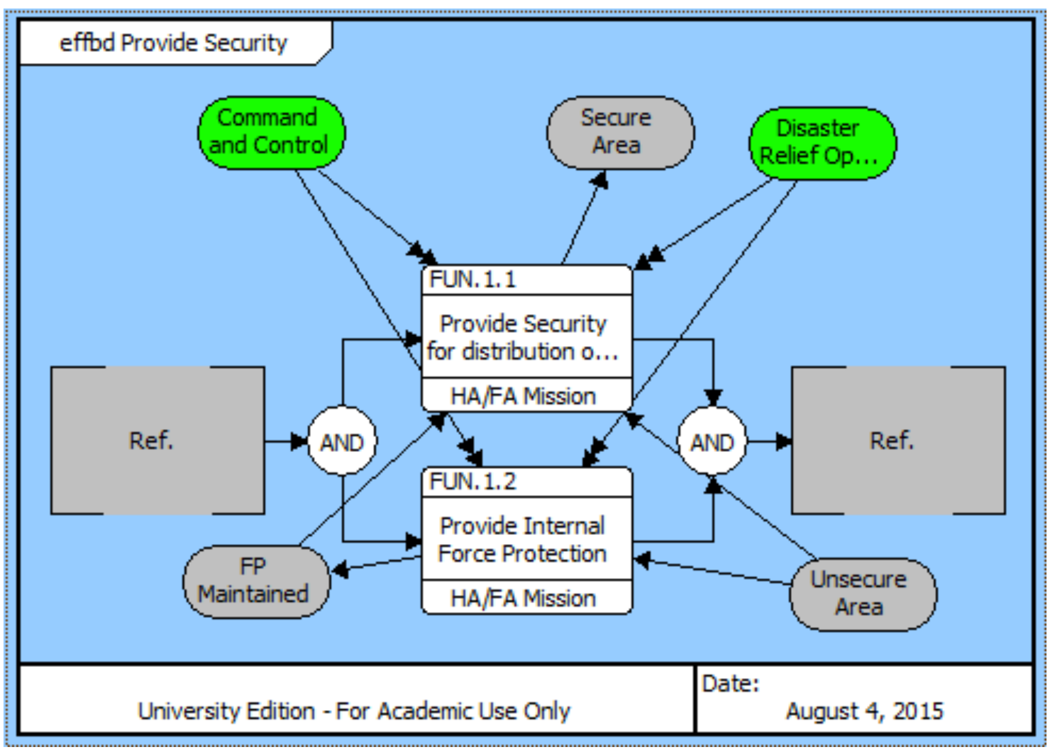


Each of the level 2 functions are supported by level 3 functions. There are 10 level three functions identified in this study. These level three functions establish what Parnell calls objectives, and ultimately, our value measurements (Parnell, Driscoll, and Henderson 2011).

b. Provide Security Function

The provide security function is one of two functions mentioned in JP3-07.6 (2001) that this research includes as a level 2 function. The provide security has two level 3 functions. The functions are to provide security for distribution and internal FP. The HA/DR mission is aware of hostile threats in the area and must provide security at the FLS and the FLSS while they are unloading aid at the sites. Once they are at the site, it is the responsibility of the HA/DR unit to ensure everyone's safety at the site in conjunction with the local security forces. The crosswalk of functions is described later in the chapter to demonstrate how level 3 functions indirectly support other level 2 functions. The HA/DR unit is also responsible for providing its internal force protection. This function is for situations when the connectors are at neither a FLS nor a FLSS. The two functions may also be conducted simultaneously due to the continuing nature of the operation. The green and grey circles represent inputs and outputs of the function. It is discussed further in the allocation section later in this chapter. Figure 45 outlines the security functions.

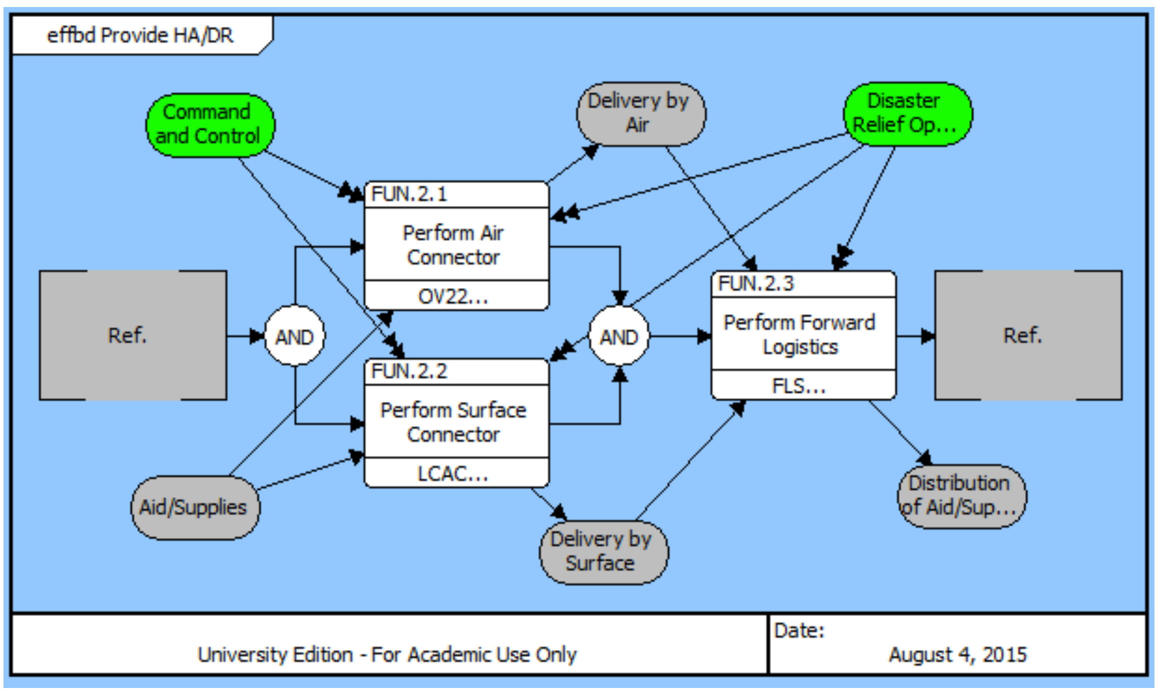
Figure 45. Provide Security Functions



c. *Provide HA/DR Function*

The HA/DR function is the other level 2 function mentioned in JP 3-07.6 (Department of Defense 2006) added as a part of this research. It is the function that performs the primary HA/DR mission. It has three level 3 functions, perform air connector functions, perform surface connector functions, and perform forward logistics functions. The EFFBD shows that the two-connector functions are conducted in parallel while the forward logistics function is performed following the two. The air connector delivers aid by aircraft to FLSS when other transportation means from the sea base are not possible. The surface connector function delivers aid to the FLS near coastal waters. The forward logistics function is to aid the flow of aid from the HA/DR mission units to the local population. Figure 46 shows the flow of functions to provide HA/DR.

Figure 46. Provide HA/DR Functions

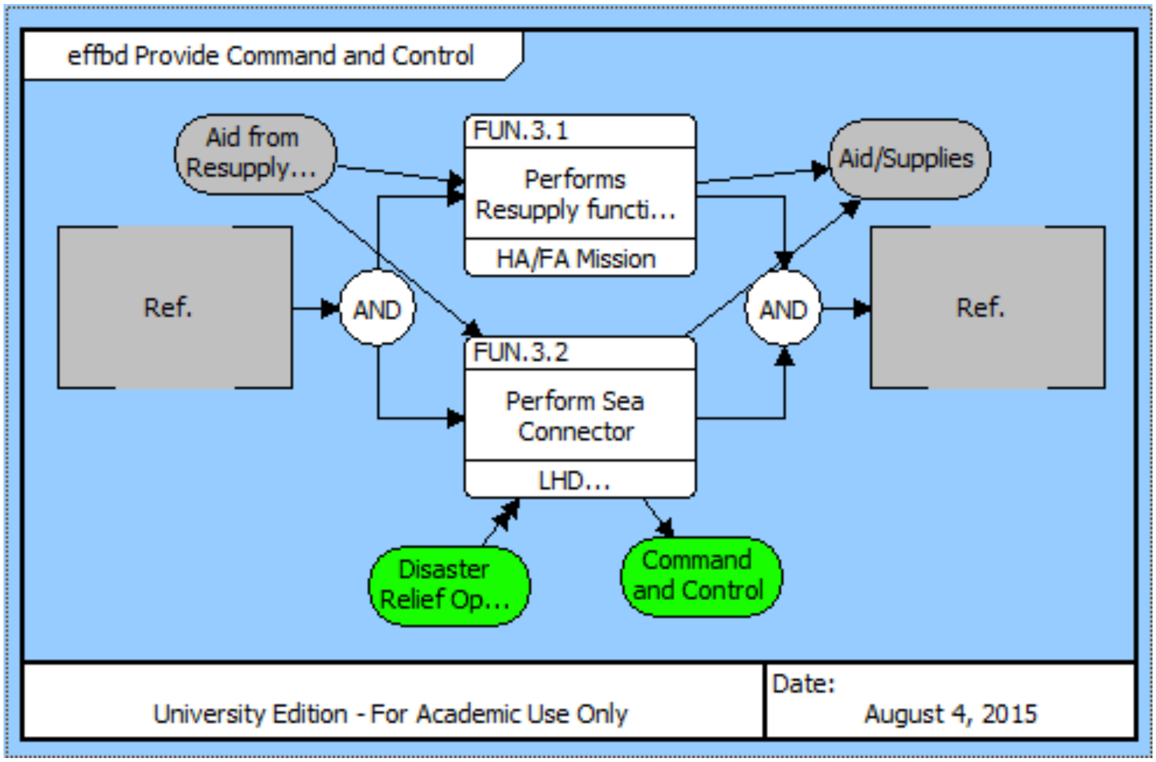


3. Provide Command and Control Function

The C&C function has two level 3 functions. The C&C has two functions, receive supply from a higher logistical station and perform the duties as a sea connector. The

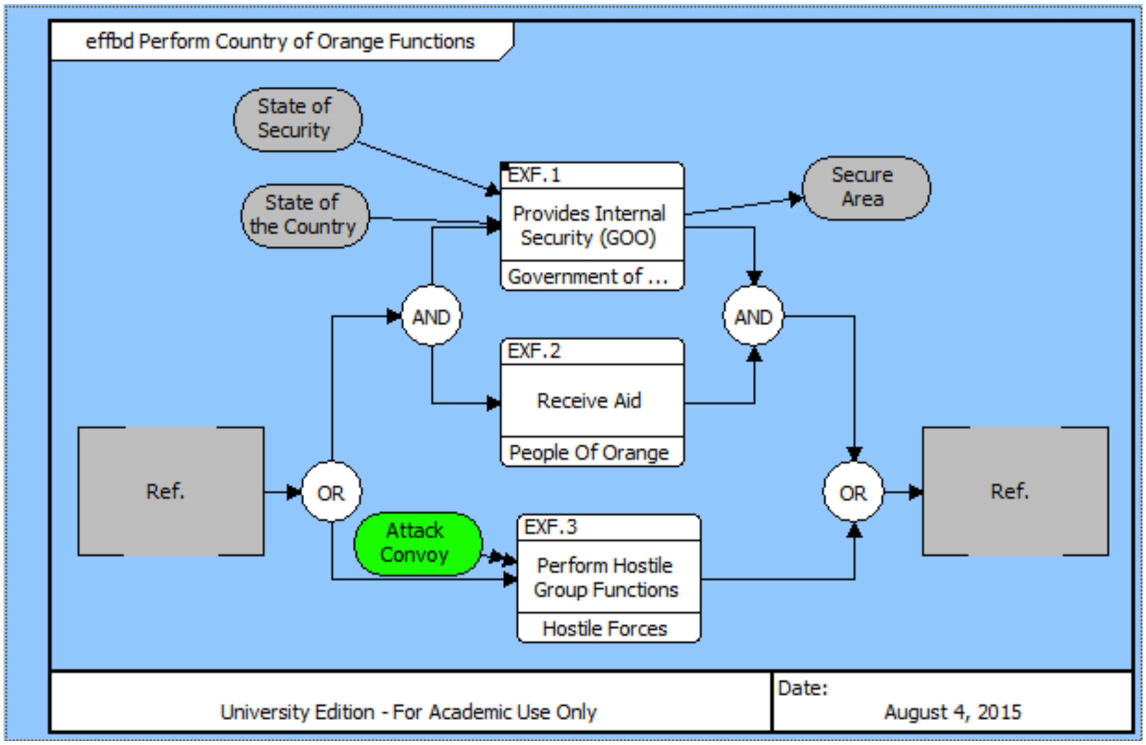
C&C function ensures that the aid for the population of the COO is first received by the sea connectors and is distributed to the air and surface connectors. Figure 47 shows the flow of functions required to provide C&C.

Figure 47. Provide Command and Control Functions



As previously mentioned, the functions of the COO are of the external system. However, ICoMM identifies the functions of the COO as a part of the overall function of providing regional security. There are three level 3 functions associated with the COO: provide internal security by the GOO, receive aid, and perform hostile. Functions EXF.1 and EXF.2 are performed in parallel. Function EXF.3 is depicted as an OR in a white circle to show that it is a function performed as a part of the function of COO, but not in conjunction with the other two. The allocated architecture presented later in the chapter shows that hostile forces opposing the GOO also has functions that impact the system. Figure 48 shows the external system's flow of functions, specifically for the COO.

Figure 48. Provide Country of Orange Functions



4. Tracing Functions to Requirements

The input and output requirements were derived from the requirements identified in section C4. The inputs are needed prior to the execution of a simulation and the outputs are the results of post simulation. Table 4 shows an initial list of input and output requirements to provide traceability of functions. The input and output requirements also include traceability to the external functions.

Table 4. Traceability from Input to Output Requirements to Functions

Functions	Input/Output Requirement					
	Input Requirements		Output Requirements		Functional Requirement	External Interface Requirement
	The COO will request aid	Hostile Forces maybe present	The HA/DR mission will deliver Aid	HA/DR mission will provide internal security	The HA/DR mission will have central C&C	The COOwill contact US & UN Reps for updates
FUN 0. Provide Regional Security	X	X	X	X	X	X
FUN 1. Provide Security		X		X		
FUN 1.1 Provide security for distribution		X		X		
FUN 1.2 Provide Internal Force Protection		X		X		
FUN 2. Provide HA/DR	X		X			
FUN 2.1 Perform Air Connector	X	X	X	X		
FUN 2.2 Perform Surface Connector	X	X	X	X		
FUN 2.3 Perform Forward Logistics	X	X	X	X		
FUN 3. Provide Command and Command	X		X		X	
FUN 3.1 Perform Resupply Functions	X		X			
FUN 3.2 Perform Sea Connector	X		X			
FUN 4. Provide Infrastructure Repair						
EXF 0. Perform Country of Orange			X			X
EXF 1. Provide Internal Security		X				X
EXF 2. Receive Aid			X			X
EXF 3. Perform Hostile Group Functions		X				X

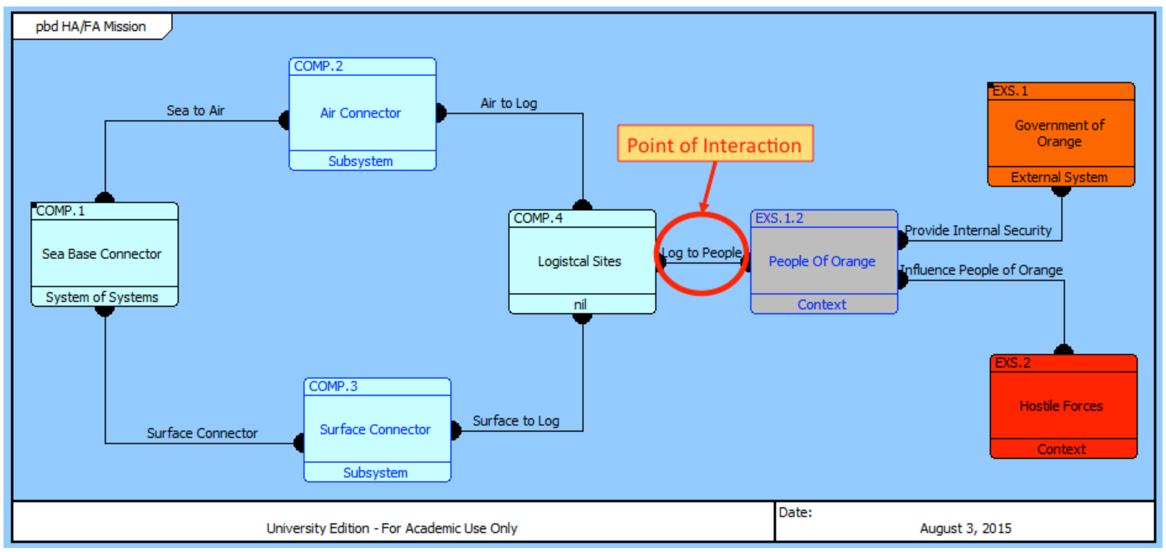
5. Physical Architecture

The physical architecture's purpose is to identify all the physical components that make up the system. ICoMM also identifies the components of the external system to be included in the physical architecture. The purpose of both the system and external system components are to meet the fundamental objective of the mission, which is to provide regional security.

Figure 49 shows the components of the system that performs the functions and the relationships of the components to each other. There are four major components in the system and three in the external system. ICoMM identifies the point of interaction between the two systems. The point of interaction is important because it is where the

two systems come in contact. For an observable system, the interaction between two systems can be observed and data can be collected. However, for a NOS, the interaction is not observable and no data is available. For example, the flow of interaction between the components of the system can be observed and the forecasted output in sync with the actual output. However, the outcome at the point of interaction between the system and the external system is less predictable. The system may deliver enough aid with no delay, but the reaction of the people may not be as forecasted.

Figure 49. Physical Architecture and the Point of Interaction



The physical architecture also has a physical hierarchy that describes the hierarchy of the components. The MEU assigned to the HA/DR mission includes various platforms to perform the required functions. The MEU includes three different amphibious warships serving as sea connectors; LHD, LPD, and the LSD. There is one of each class on the amphibious ships. Each of the ships also either carries air connectors, surface connectors, or both. The air connectors include a MH53 transport helicopter, a SH60 medium utility helicopter, and a MV-22 tilt-rotor transport. The purpose of the air connectors is to deliver aid to the FLSS that are remote and far away from access to the sea. The surface connectors include LCAC and LCU. The purpose of the surface

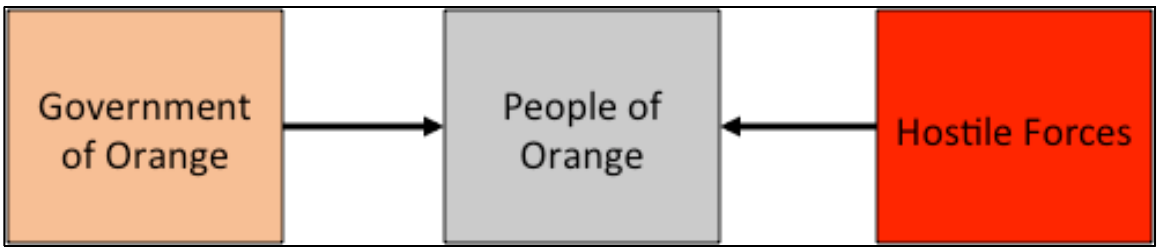
connector is to deliver aid to the FLS within proximity of the sea. Figure 50 graphically outlines the distribution of vehicles among the sea connectors.

Figure 50. Distribution of Air and Surface Connectors among the Amphibious Ships

ICoMM identifies the external physical architecture as the composition of the people of COO, GOO, and hostile forces. As seen in Figure 51, both the GOO and the hostile forces converge on the people of Orange. The system also interacts with the people. The convergence to one component has a strong indication that this is the center of gravity of the operation. Conceptual planning of the center of gravity and understanding how it impacts the overall mission is an important aspect of military operations (Department of the Army 2014). The military center of gravity is defined by JP 5-0 as "a source of power that provides moral or physical strength, freedom of action, or will to act" (Department of Defense 2011, III–22). Identification of the military center

of gravity is important in this scenario because it provides better insight into the selection of the point of interaction. The identification of the military center of gravity also supports the idea that the hostile forces conduct its operations to influence the population to turn against the GOO.

Figure 51. Components of the External System



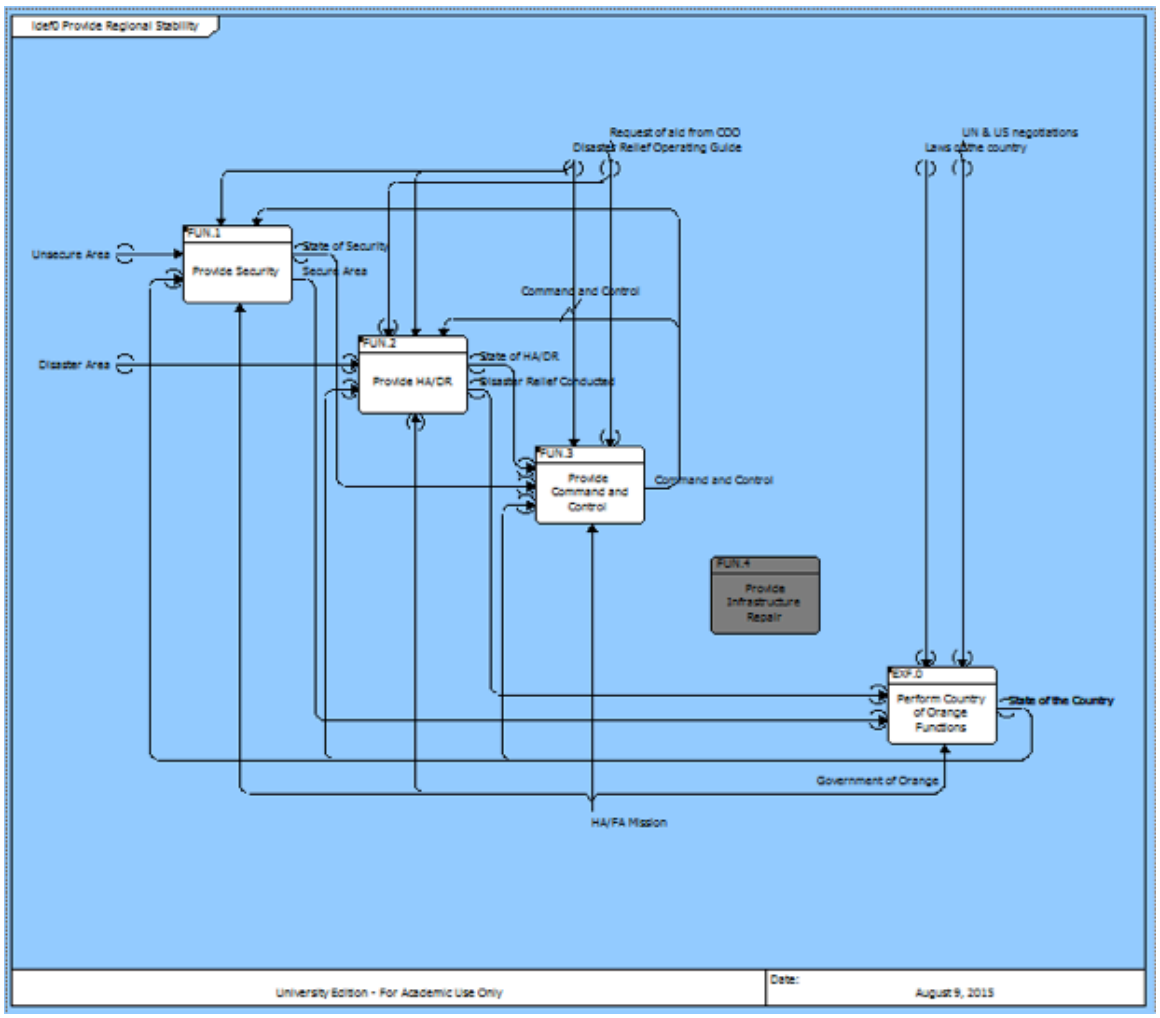
6. Allocated Architecture

The allocated architecture provides the overall picture of the complete system. As previously mentioned, the external system is also included to show the interaction with the system. The functional and physical architectures previously discussed are the basis for the building of the allocated architecture. The functions identified on the functional hierarchy are linked to the components in the physical architecture.

The traceability provided by the allocated architecture is shown on an IDEF0 model. The IDFE0 model uses the functional and physical decompositions to assign to the components to the functions. The link is made at every level. The IDEF0 model describes not only the link between the component and the function but also the inputs and outputs of the model, as well as the controls the functions will be performing. The IDEF0 model has four main components: inputs, control, outputs, and mechanisms to describe system. Figure 52 shows the highest-level IDEF0 diagram supporting the fundamental objective of providing regional security. As seen in the functional hierarchy, five sub-level functions must be accomplished to meet the fundamental objective. Function 4, provide infrastructure repair, is not included in this research because it is outside of the scope of the military's HA/DR mission. All the other functions are part of

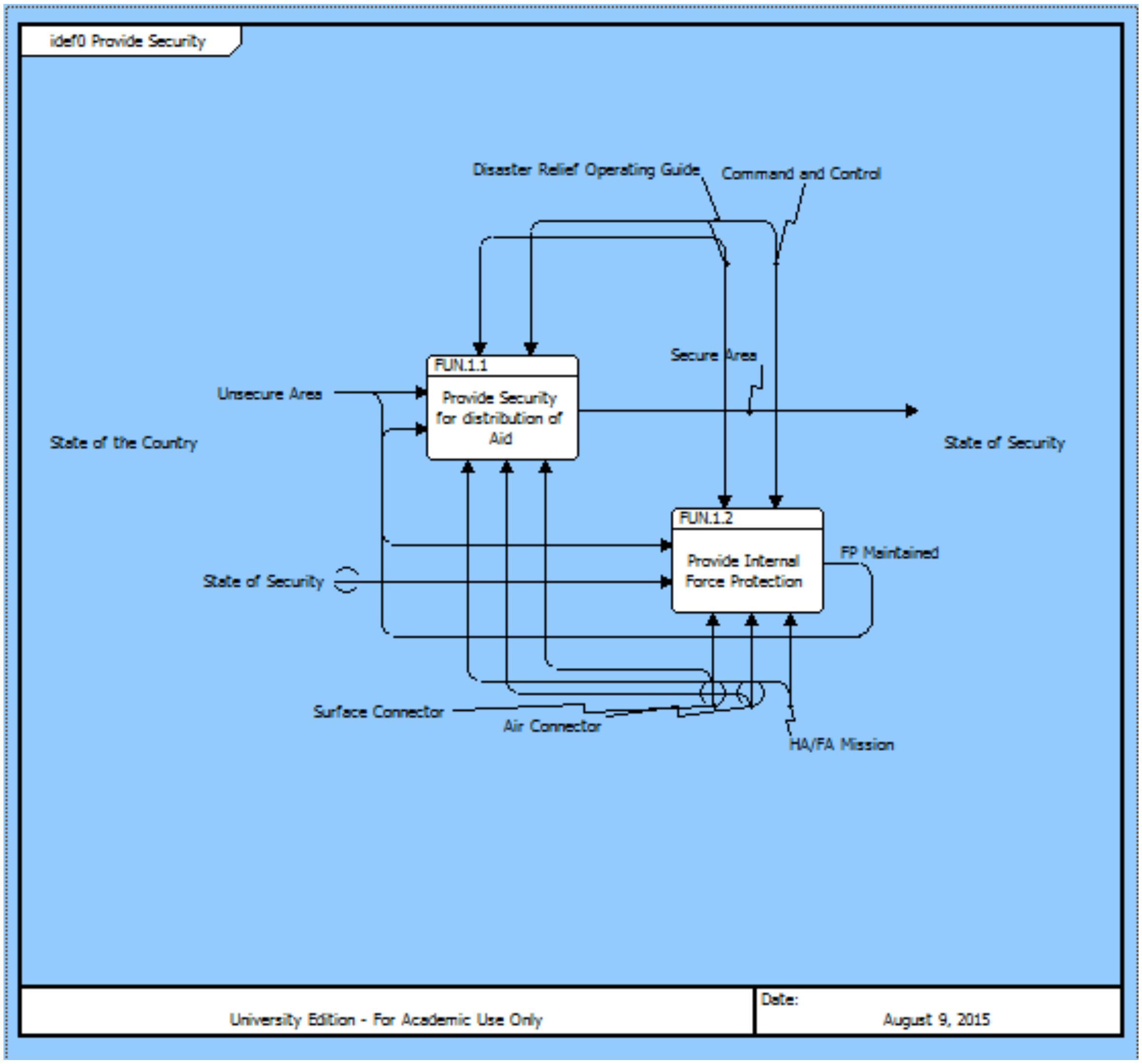
the HA/DR mission to include the external function. The mechanism or the component that executes the functions one through three is the HA/DR mission or also known as the HA/DR mission unit. The external system, EXF.0 perform COO functions, also has the HA/DR mission that provides support to the function. However, the primary component to EXF.0 is the GOO. All the components of the system are controlled by the disaster relief-operating guide from the DOD and at the request of the COO. This is scope of the HA/DR mission the MEU will be executing. The following sections discuss each of the IDEF0 components in greater detail.

Figure 52. IDEF0 Diagram of Provide Regional Stability



The provide security section has two level 2 functions. Figure 53 shows that two functions are to provide security for the distribution of aid and internal protection. The functions are executed by the components of the overall HA/DR mission and by both the surface connector and air connector. These components perform both security and internal FP throughout the HA/DR mission. Both security and internal FP functions are performed because the connectors carry FP personnel during the execution of the missions. Once they reach their destinations of either FLS or FLSS, the personnel of the connectors provide security during the distribution of aid in conjunction with the country of Orange security forces (COSF). The control portion of the provide security IDEF0 is following the disaster relief guide, which provides guidance during the execution of the HA/ DR mission. ICoMM uses the control of the IDEF0 as providing the context by defining the scope and boundary of their mission. Ultimately, the C&C element oversees the functions of security and FP. Any changes in their state are reported to the sea base to measure progress. The input for FUN.1.1 is an unsecured area and the output is a secured area. The input for FUN.1.2 is the state of security during the operation and the output is that FP is maintained. It is also to note that the output of FP also provides an input for FUN.1.1. It is because the level of FP has an effect on the security during the distribution of aid. Should the level of FP be at a level where the connectors could not protect it from the enemy, then the mission would have to be altered to meet the requirement to provide security.

Figure 53. IDEF0 Diagram of Provide Security

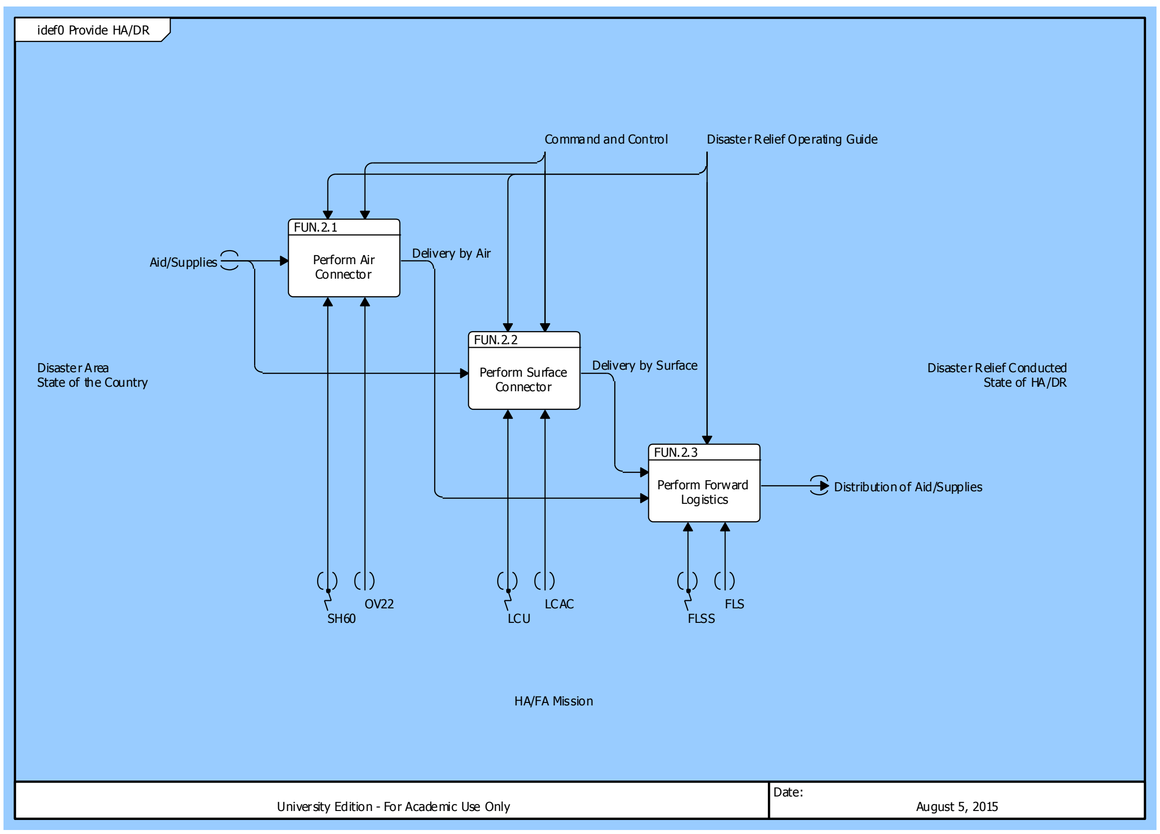


7. Provide HA/DR

The provide HA/DR function has three level 2 functions. The functions of perform air connector missions, perform surface connector missions and to perform forward logistics are previously identified. The functions are all controlled by the disaster relief operating guide. However, the C&C of the mission provide context to only two of the functions as a mean of control. There are also only one input to each of the functions, the aid and supplies of the mission. Both of the connectors receive aid supplies from the sea base and perform their functions to deliver the aid supplies to the FLS and FLSS. The

aid delivered by the connectors is the inputs to perform forward logistics and the output is the distribution of the aid supplies to the local population. The mechanisms assigned to perform the air connector functions are the MH 53, MV22 and the SH60 aircrafts. They are responsible for carrying the aid supplies to the FLSS. The mechanisms executing the surface connector functions are the LCAC and the LCU. The surface connectors deliver aid to the FLS. The actual FLS and the FLSS performs the functions of the forward logistics to ensure the flow of aid supplies from the connectors are distributed to the local population. Figure 54 shows the IDEF0 model that traces the ICOM.

Figure 54. IDEF0 Diagram for Provide HA/DR

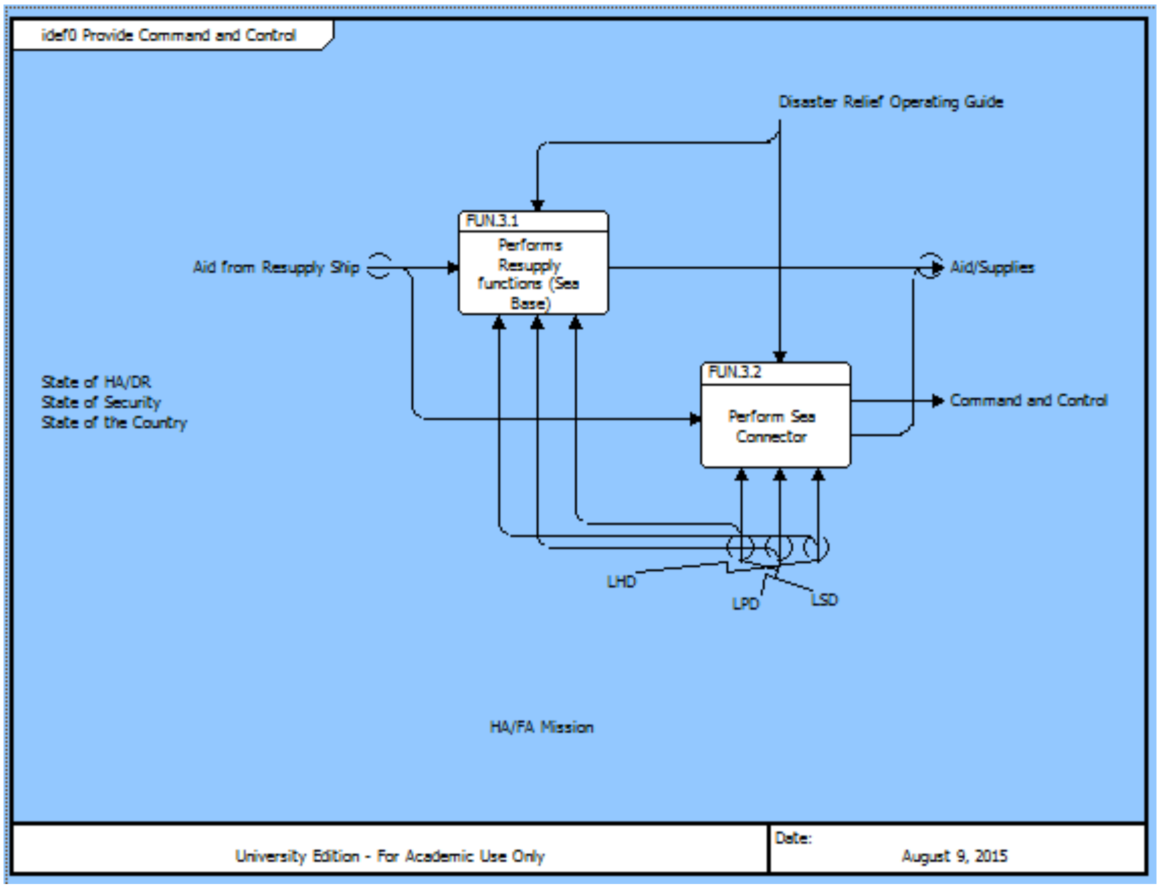


a. Provide Command and Control

Figure 55 shows the IDEF0 model for the C&C function. There are two level 2 functions that support the C&C function, perform resupply functions as the sea base and

perform sea connector function. The LHD, the LPD, and the LSD amphibious ships perform both functions. Both inputs are the resupply from resupply ships that are for both internal supply needs and to distribute to the COO.

Figure 55. IDEF0 Diagram for Provide Command and Control

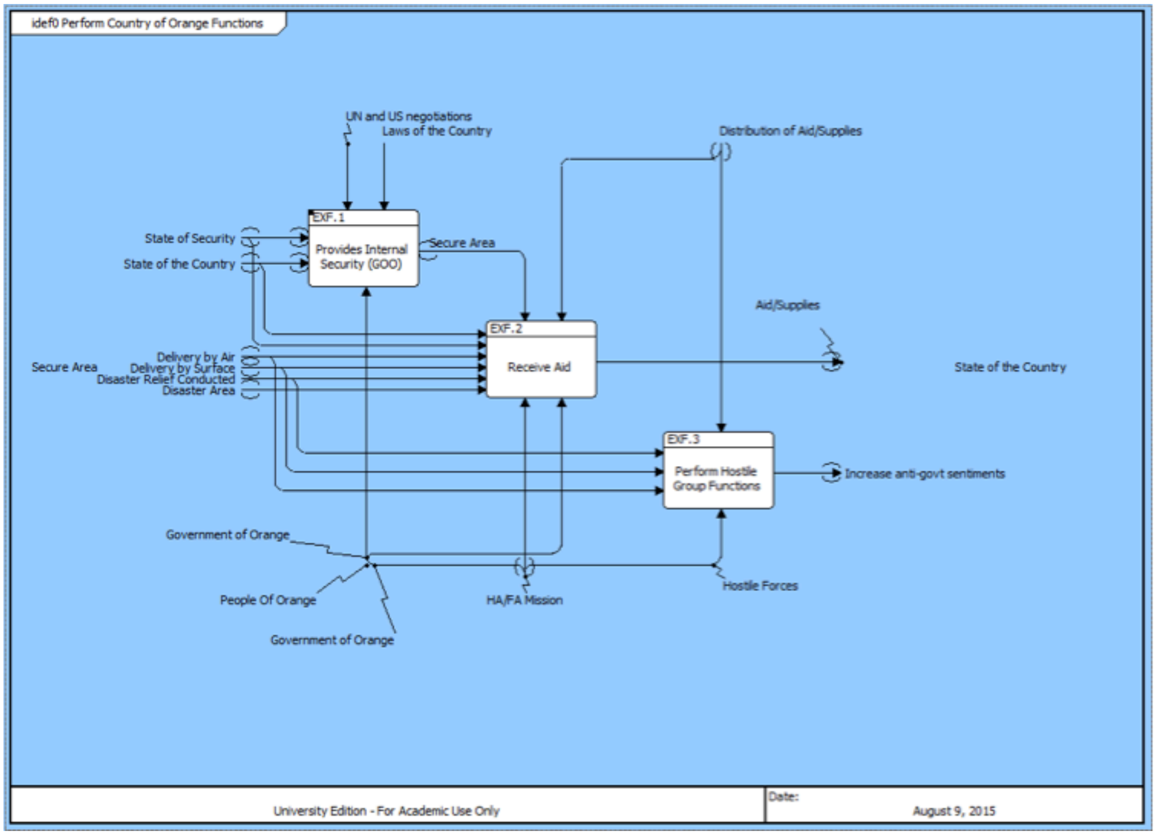


b. Perform Country of Orange Functions

ICoMM also investigated the IDEF0 model of the external system as we did of the system. The IDEF0 model for the external system is shown in Figure 56. An IDEF0 model must also be made for the external system to understand its functions and the components that will execute the external system functions. The external system's overall function of performing COO functions has three sub-level functions: provide internal security for the GOO, receive aid, and perform hostile group functions. The functions

were described in detail previously in section B1 of this chapter. The following sections discuss the allocation of the sub-level functions to the components in greater detail.

Figure 56. IDEF0 Diagram of Perform Country of Orange Functions

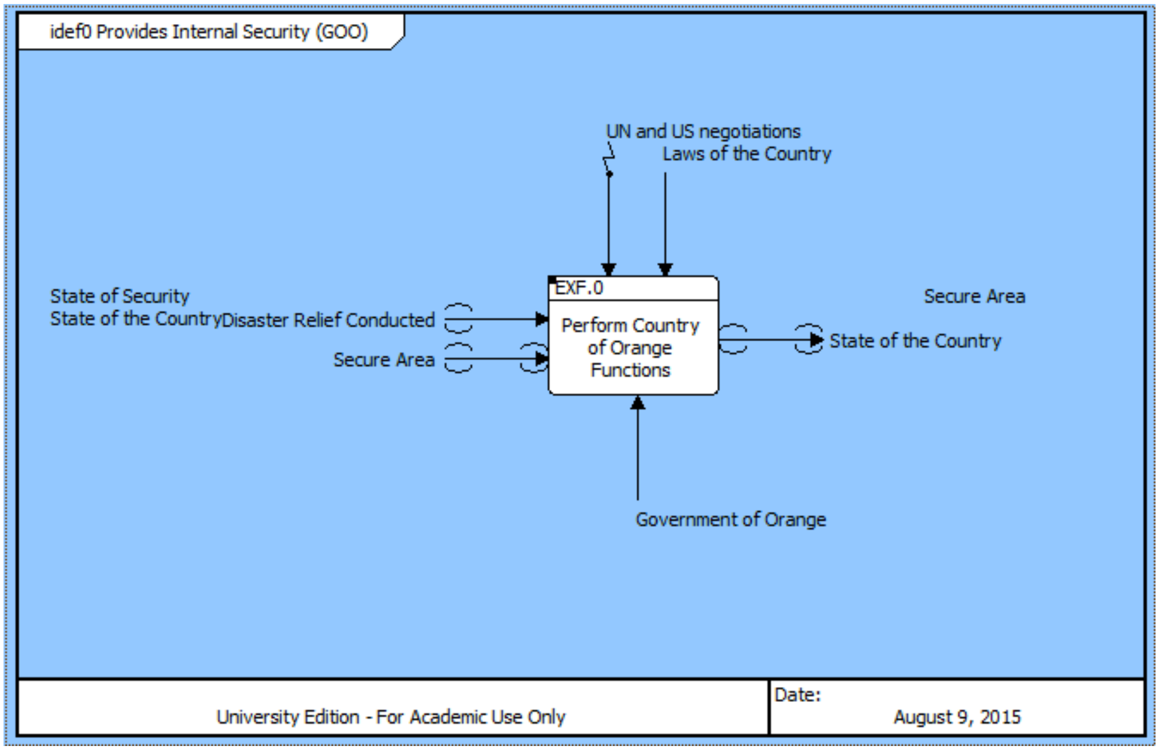


c. *Provide Internal Security*

The first external system function is to provide internal security. The GOO executes this function. Figure 57 shows the controls for this function are the UN and U.S. negotiations to assist the COO and the internal laws of the country. The UN and U.S. organizations establish the scope and boundary of the actions of the HA/DR mission unit, as well as the expectation of the GOO, while the law governing the country limits the actions of its internal forces. The inputs are the actions of the HA/DR mission of conducting relief and providing a secure area. The output of this function is the state of the country. The state of the country may be on pace to a quick recovery or recovery may

be delayed due to an increase of hostile activities. The state of the country is an indicator measured to provide information to the stakeholders to refine and execute plans based on the state of the country.

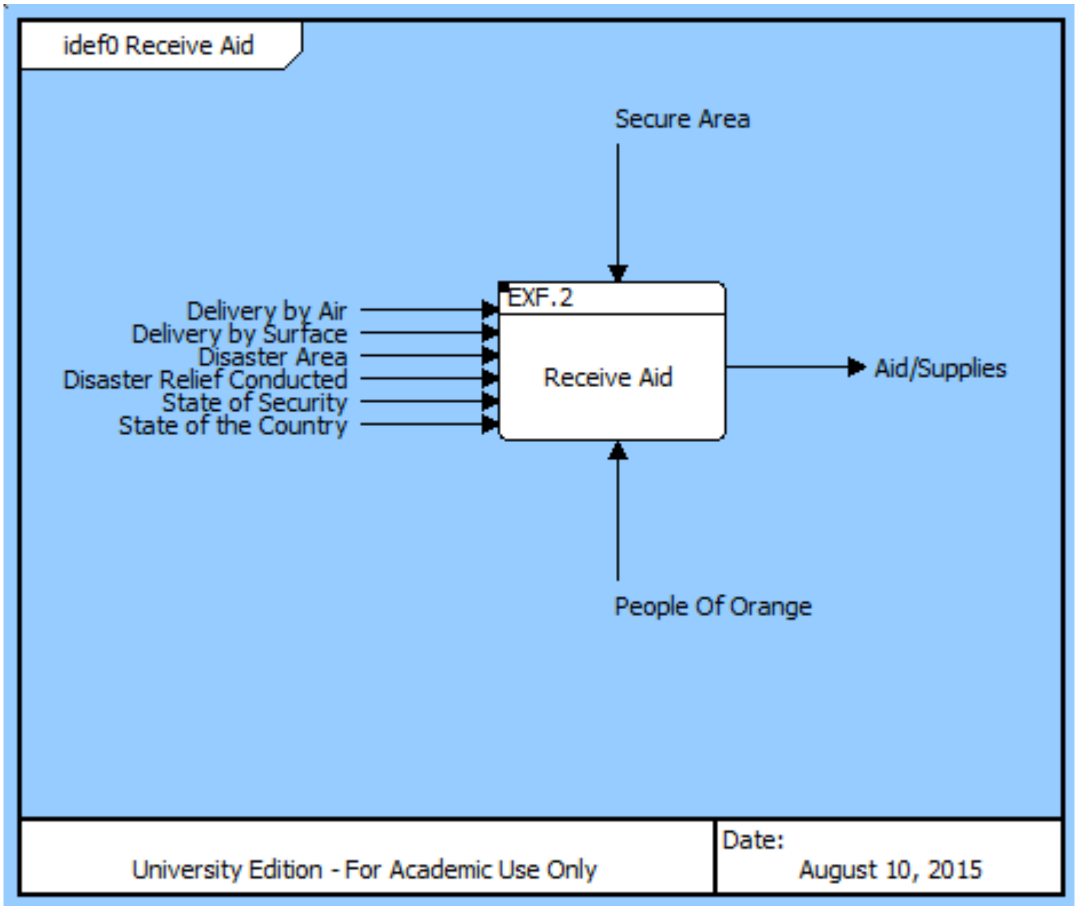
Figure 57. IDEF0 Diagram for Provide Internal Security (GOO) Functions



d. Receive Aid

The following external system function is to receive aid, as seen in Figure 58. As simple as it may sound, it is important to maintain a good measure of the amount of aid flowing into the FLS and the FLSS by the HA/DR mission unit. Therefore, the inputs into this function are the deliver mechanisms, the disaster area, and the state of both the security and overall country. The output is the aid supplies distributed to the people. The component that receives the aid is the local population. A secure area and the distribution of supplies control the function.

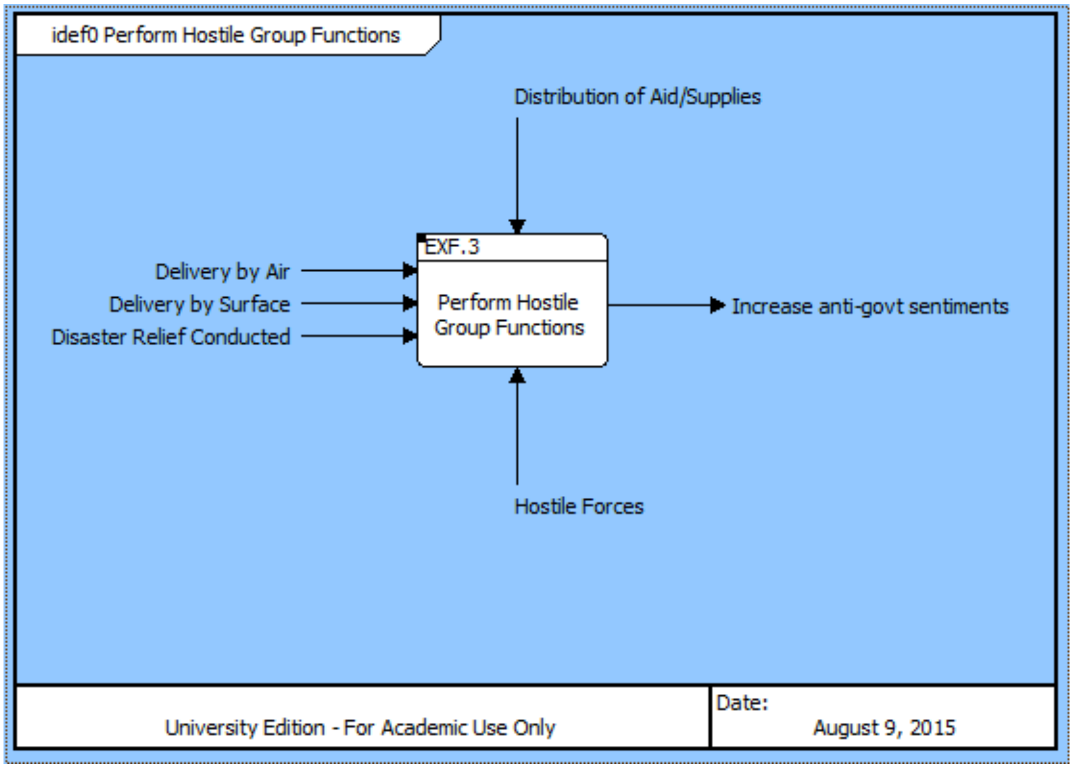
Figure 58. IDEF0 Diagram for Receive Aid



8. Perform Hostile Group Functions

As previously mentioned, the hostile forces are also components that influence the HA/DR mission. Figure 59 shows perform hostile functions conducted by the hostile forces within the COO. It is controlled by the distribution of aid supplies by the HA/DR mission units. The hostile group forces must act if the amount of distribution increases. If the amount of distribution decreases, then the actions of the group may have had success in their efforts. The inputs are the delivery of aid from both air and sea connectors. It also includes whether disaster relief was conducted. Performing hostile group acts on the inputs produces increases anti-government sentiments. This action must be monitored due to its effect of reaching the fundamental objective of providing regional security.

Figure 59. IDEF0 Model for Perform Hostile Group Functions



E. ESTABLISHING THE VALUE OF THE ALLOCATED FUNCTIONS

ICoMM equates the top-level function as the "fundamental objective". The fundamental objective is the overall strategic mission to provide regional security. "Means objectives" or sub-level objectives also support the listed functions. The means objectives show the preferences regarding the values intended by the stakeholders (Parnell, Driscoll, and Henderson 2011). The following values are the means objectives that are the quantitative method to evaluate the system performance and identify progression of the system toward the achievement the fundamental objective. The structure shown in Table 4 is the basis for measures of effectiveness and measure of performance (MOP) in military operational assessment process. Tables 5 and 6 show the value hierarchy for the system and the external system. The table lists the top-level function. As previously mentioned, the top-level function is also the fundamental objective of the HA/DR mission. The two rows below are the level 2 and level 3 functions. The following rows alternate between means objectives and the measures. The

means objective show whether the values should be maximized or minimized. The measures directly below the means objectives show the measures that must be taken to show status of the mission. Table 5 shows means objectives and the measures for the system. It is listed under the systems functions. Each column represents the direct support of objectives and measures to the functions above.

Table 5. System Means Objectives and its Measures

FUN 0. Provide Regional Security						
FUN 1. Provide Security		FUN 2. Provide HA/DR			FUN 3. Provide Command and Control	
FUN 1.1 Provide security for distribution	FUN 1.2 Provide Internal Force Protection	FUN 2.1 Perform Air Connector	FUN 2.2 Perform Surface Connector	FUN 2.3 Perform Forward Logistics	FUN 3.1 Perform Resupply Functions	FUN 3.2 Perform Sea Connector
FUN 1.1.1. Max number of troops	FUN 1.2.1. Max number of troops	FUN 2.1.1. Max number of air frames	FUN 2.2.1. Max number of surface vehicles	FUN 2.3.1. Max amount of aid flow	FUN 3.1.1. Max amount of resupply	FUN 3.2.1. Max command and control
Number of troops by specialty	Number of troops by specialty	Number of different aircrafts (type)	Number of different surface crafts (type)	Amound of aid into FLS &FLSS (lbs/type)	Amount of resupply (lbs/type)	No loss of contact with deployed element
Fun 1.1.2. Max number of equipment	FUN 1.2.2. Max number of equipment	FUN 2.1.2. Max number of aid flow	FUN 2.2.2. Max number of aid flow	FUN 2.3.2. Max amount of storage	FUN 3.1.2. Max amount of storage	FUN 3.2.2. Max contact with Govt of Orange
Number of equipment by type	Number equipment by type	Amount of aid delivered per day (lbs)	Amount of aid delivered per day (lbs)	Amount of aid stored (lbs/type)	Amount of stored (lbs/type)	Number of contact with GOO
		FUN 2.1.3. Max Payload	FUN 2.2.3. Max Payload	FUN 2.3.3. Max distribution		
		Amount of payload (lbs)	Amount of payload (lbs)	Amount of aid distributed (lbs/type)		
		FUN 2.1.4. Min travel time	FUN 2.2.4. Min travel time			
		Travel time (kph)	Travel time (mph)			
		FUN 2.1.5. Min fuel usage	FUN 2.2.5.Min fuel usage			
		Amount of fuel used (gal / hr)	Amount of fuel used (gal / hr)			
		FUN 2.1.6. Min load time	FUN 2.2.6. Min load time			
		Time to load aircraft (min)	Time to load surface craft (min)			
		FUN 2.1.7. Min unload time	FUN 2.2.7.Min unload time			
		Time to unload aircraft (min)	Time to unload surface craft (min)			
		FUN 2.1.8. Max operating time	FUN 2.2.8. Max operating time			
		Time to operate aircraft (flt hrs)	Time to operate surface craft (flt hrs)			
		FUN 2.1.9. Max number of trips to FLSS	FUN 2.2.9. Max number of trips to FLS			
		Number of trips	Number of trips			

Functions

Value Measures

Table 6 shows the means objectives and the measures for the external system. The functions for the COO support primarily the requirement of receiving aid, as seen in the requirements hierarchy. In the functional hierarchy, the function of receiving aid supports the higher function of performing the function of the COO along with providing internal security and performing hostile group functions. An example can be seen in Figure 42. The means objectives and the measures support the functions of the three level 3 functions, which support the functions of the COO.

Table 6. External Systems Means Objectives and Measures

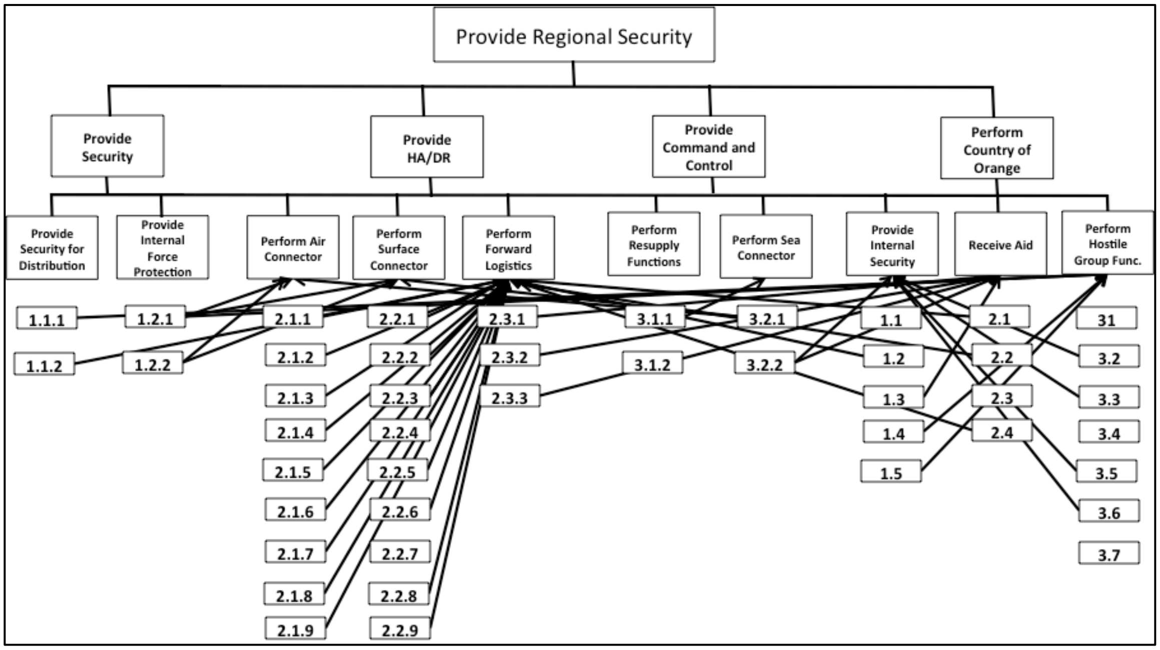
FUN 0. Provide Regional Security		
EXF 0. Perform Country of Orange		
EXF 1. Provide Internal Security	**EXF 2. Receive Aid**	**EXF 3. Perform Hostile Group Functions**
EXF 1.1. Max Security forces	EXF 2.1. Max Aid received	EXF 3.1.Max number of anti-govt forces
Number of security force troops	Amount of aid (lbs / type)	Number of anti-govt forces
EXF 1.2. Max Distribution of COSF to FLS &FLSS	EXF 2.2. Max aid distributed to population	EXF 3.2. Max attack on govt facilities
Number of security forces at FLS & FLSS	Amount distributed (lbs / type)	Number of attacks
EXF 1.3. Max interaction with local poplulation	EXF 2.3. Min distance poulation travel	EXF 3.3. Max prevention of aid to population
Number of engagements with population	Distance traveled to receive aid (miles)	Number of attacks
EXF 1.4. Max interaction with hostile forces	EXF 2.4 Max contact with HA/DR unit	EXF 3.4. Max interaction with local population
Number of engagements with hostile forces	Number of contacts with HA/DR unit	Number of contact with local population
EXF 1.5 Min casulaties		EXF 3.5. Min attack on population
Number of casualties		Number of attacks
		EXF 3.6. Min interaction with Govt Forces
		Number of engagements with GOO
		EXF 3.7. Min casualties
		Number of casualites

Functions

Value Measures

Figure 60 is a crosswalk of the measures to functions to the objectives, and ultimately, to the fundamental objective. The objectives are lined up below the functions it supports. The arrows depict the different functions that objectives may have an effect on other objectives. For example, objective 2.1.3 maximizes the amount of payload by aircraft, which directly supports the perform air connection function that has an effect on the function of performing forward logistics. The inability of the air connectors to deliver maximum payload of aid to the forward logistics sites will hinder the forward logistics functions and not obtain the means objectives of maximizing the amount of storage and distribution of good to the local population. It also affects the external system and its function of receiving aid. The lack of aid delivered to the population of Orange could potentially assist hostile groups, and ultimately, have an inverse effect on the fundamental objective of providing regional security. It is important to identify adversarial functions and crosswalk the measures that have the possibility of hindering the success of the operation.

Figure 60. Crosswalk of the Means Objectives to the Functions



SMEs are solicited to provide their value of the different measures after performing the cross walk between the objectives and functions. The inputs from the SMEs demonstrate the values they feel are important to the mission. The result of this process will capture the most important functions and objectives for the system (Parnell, Driscoll, and Henderson 2011). The measures are also weighted to show the potential impact the function will have on the overall mission. The DM is the commander of the mission and relies on SMEs to provide weights to the best of their knowledge.

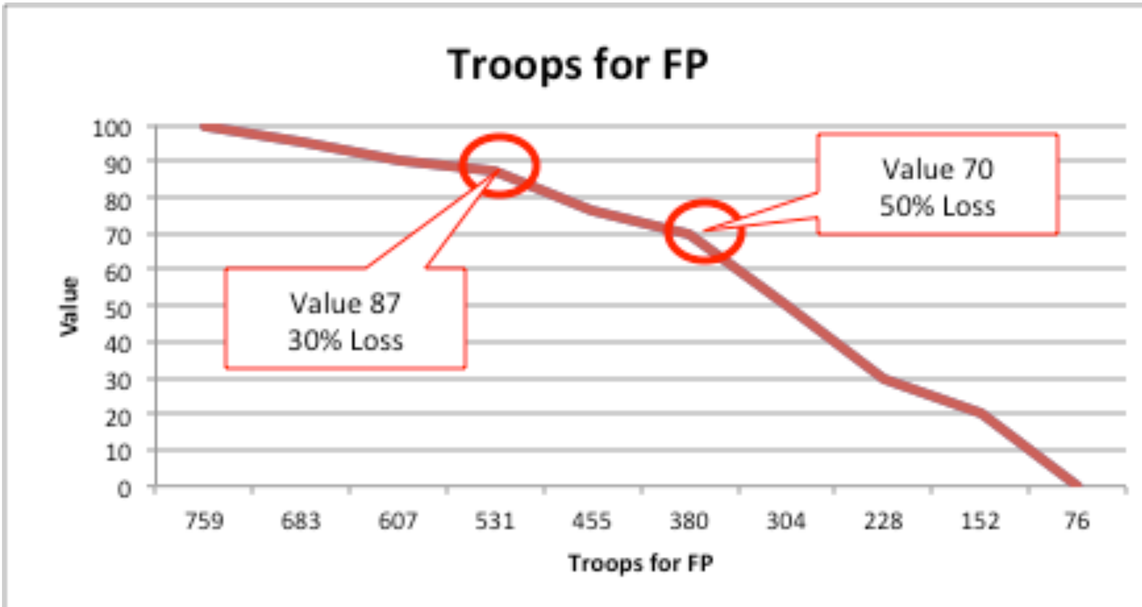
Table 7 is an example of the solicitation taken from the SMEs of the troops dedicated for FP. The number of troops dedicated FP purposes is 759. A third of the 2,300 total troops for the mission are dedicated to FP. The stakeholder is provided with a degradation of troops in 10% increments from the maximum for a protection number of 759. The stakeholder is asked to rate the values from 0 to 100. The numbers do not have to be in increments of 10. The table shows that there is a large drop in value when the number of troops drops from 380 to 304. The number of troops at 380 is 50% from the maximum force and the stakeholder indicates that the force may not be able to operate below 380.

Table 7. Example of Troops for Force Protection Value Solicitation from Stakeholders

Troops for Force Protection	Value
759	100
683	95
607	90
531	87
455	76
380	70
304	50
228	30
152	20
76	0

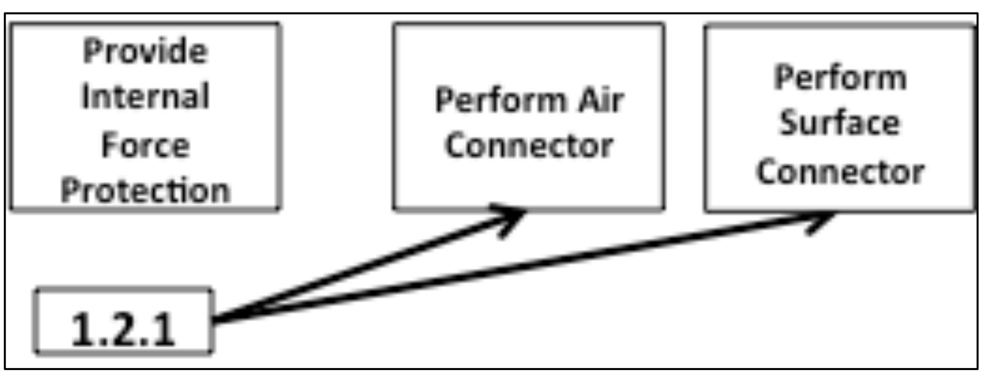
The information Table 7 can also be depicted in a graphical manner. Figure 61 shows a concave graph describing a decrease from an optimal number of troops to the least desirable number. All the value measure graphs are monotonically increasing or decreasing. The importance of the graph is that a DM or any other stakeholders can quickly assess the situation and make decisions based on the predetermined points of decision. These are identified on the inflection points circled on the graph. The first inflection point is at value 87 when the mission has taken a loss of 30 percent for the troops for the FP measure. The second inflection point is at value 70 when there is a 50% loss of troops. This number would be a warning sign to the commander to either choose a different course of action or begin requesting replacements. The number of troop loss is not only for contact loss but also due to sickness or other administrative issues.

Figure 61. Value Measure Number of Troops for Force Protection



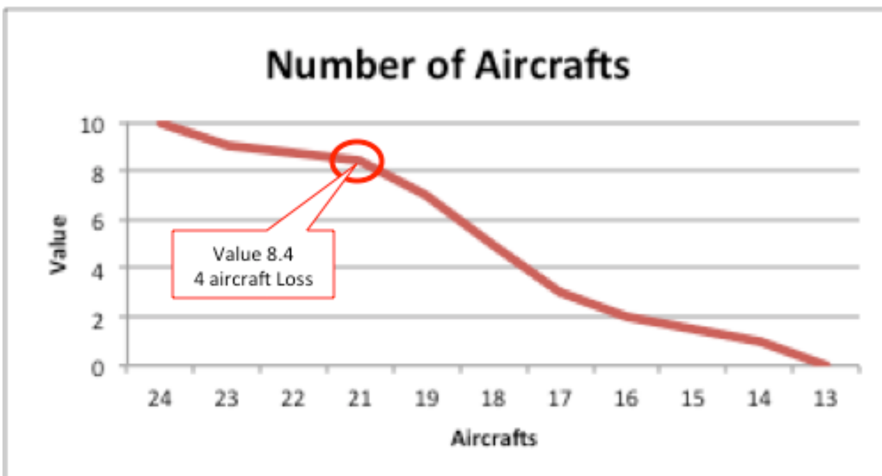
Looking back at the objectives to functions crosswalk, ICoMM identified that objective 1.2.1, maximize number of troops for FP, also have indirect effects on functions perform air connector and perform surface connector. The decrease of the number of troops for force protection has the potential to inhibit the two-connector functions. The cross walk is shown in Figure 62.

Figure 62. Maximize Number of Troops for Force Protection Objective Crosswalk



After tracing the potential impact of the decrease of the number of troops for FP to perform air connector, we will take a look at one of the air connector objectives that may potentially affect it. The objective is to maximize the number of aircraft that will be involved in the HA/DR mission. A total of 24 aircrafts will be participating in the mission. The number of aircraft that can be flown in the mission is also dependent on the amount of FP troops available to provide security. The reduction of FP troops also means a reduction in participating aircrafts. The decrease in the value is based on each aircraft loss. The inflection point is at value 8.4 with the loss of four aircrafts. The loss of an aircraft could be due to normal maintenance or loss during operation. Anything below the loss of four aircrafts will not be acceptable to the commander, as shown in Figure 63.

Figure 63. Value Measure of Number of Aircrafts for HA/DR Mission



Once all the value measures are identified and graphed, global weights are assigned to the measures. The global weights enable the SMEs to identify the objectives they feel will have the most impact during the operation. While all the measures are tracked, the ones with greater weights receive greater emphasis. Table 8 shows the functions, objective, measure, the swing weights, and the global weights. The swing weights were solicited again from the SMEs to rate all the measures. The global weight measures also show the importance of the measure.

Table 8. Ordering of the Value and the Impact of the Functions

FUNCTION	OBEJECTIVE	MEASURE	SWING	GLOBAL	NORM SCORE
FUN 1. Provide Security					
FUN 1.1 Provide security for distribution	FUN 1.1.1. Max number of troops	Number of troops by specialty	64	0.0198	1.39
	FUN 1.1.2. Max number of equipment	Number of equipment by type	63	0.0195	
FUN 1.2 Provide Internal Force Protection	FUN 1.2.1. Max number of troops	Number of troops by specialty	62	0.0192	
	FUN 1.2.2. Max number of equipment	Number equipment by type	61	0.0189	
FUN 2. Provide HA/DR					
FUN 2.1 Perform Air Connector	FUN 2.1.1. Max number of air frames	Number of different aircrafts (type)	100	0.0309	2.03
	FUN 2.1.2. Max number of aid flow	Amount of aid delivered per day (lbs)	95	0.0294	
	FUN 2.1.3. Max Payload	Amount of payload (lbs)	93	0.0288	
	FUN 2.1.4. Min travel time	Travel time (kph)	85	0.0263	
	FUN 2.1.5. Min fuel usage	Amount of fuel used (gal / hr)	90	0.0278	
	FUN 2.1.6. Min load time	Time to load aircraft (min)	87	0.0269	
	FUN 2.1.7. Min unload time	Time to unload aircraft (min)	86	0.0266	
	FUN 2.1.8. Max operating time	Time to operate aircraft (flt hrs)	89	0.0275	
	FUN 2.1.9. Max number of trips to FLSS	Number of trips	97	0.0300	
FUN 2.2 Perform Surface Connector	FUN 2.2.1. Max number of surface vehicles	Number of different surface crafts (type)	84	0.0260	1.79
	FUN 2.2.2. Max number of aid flow	Amount of aid delivered per day (lbs)	99	0.0306	
	FUN 2.2.3. Max Payload	Amount of payload (lbs)	81	0.0251	
	FUN 2.2.4. Min travel time	Travel time (mph)	70	0.0217	
	FUN 2.2.5.Min fuel usage	Amount of fuel used (gal / hr)	74	0.0229	
	FUN 2.2.6. Min load time	Time to load surface craft (min)	73	0.0226	
	FUN 2.2.7.Min unload time	Time to unload surface craft (min)	71	0.0220	
	FUN 2.2.8. Max operating time	Time to operate surface craft (flt hrs)	75	0.0232	
	FUN 2.2.9. Max number of trips to FLS	Number of trips	83	0.0257	
FUN 2.3 Perform Forward Logistics	FUN 2.3.1. Max amount of aid flow	Amound of aid into FLS &FLSS (lbs/type)	98	0.0303	1.74
	FUN 2.3.2. Max amount of storage	Amount of aid stored (lbs/type)	69	0.0213	
	FUN 2.3.3. Max distribution	Amount of aid distributed (lbs/type)	68	0.0210	
FUN 3. Provide Command and Control					
FUN 3.1 Perform Resupply Functions	FUN 3.1.1. Max amount of resupply	Amount of resupply (lbs/type)	67	0.0207	1.61
	FUN 3.1.2. Max amount of storage	Amount of stored (lbs/type)	66	0.0204	
FUN 3.2 Perform Sea Connector	FUN 3.2.1. Max command and control	No loss of contact with deployed element	92	0.0285	
	FUN 3.2.2. Max contact with Govt of Orange	Number of contact with GOO	65	0.0201	
EXF 0. Perform Country of Orange					
EXF 1. Provide Internal Security	EXF 1.1. Max Security forces	Number of security force troops	55	0.0170	1.20
	EXF 1.2. Max Distribution of COSF to FLS &FLSS	Number of security forces at FLS & FLSS	54	0.0167	
	EXF 1.3. Max interaction with local poplulation	Number of engagements with population	53	0.0164	
	EXF 1.4. Max interaction with hostile forces	Number of engagements with hostile forces	52	0.0161	
	EXF 1.5 Min casualties	Number of casualties	56	0.0173	
EXF 2. Receive Aid	EXF 2.1. Max Aid received	Amount of aid (lbs / type)	96	0.0297	1.66
	EXF 2.2. Max aid distributed to population	Amount distributed (lbs / type)	92	0.0285	
	EXF 2.3. Min distance poulation travel	Distance traveled to receive aid (miles)	50	0.0155	
	EXF 2.4 Max contact with HA/DR unit	Number of contacts with HA/DR unit	60	0.0186	
EXF 3. Perform Hostile Group Functions	EXF 3.1.Max number of anti-govt forces	Number of anti-govt forces	49	0.0152	1.13
	EXF 3.2. Max attack on govt facilities	Number of attacks	59	0.0183	
	EXF 3.3. Max prevention of aid to population	Number of attacks	58	0.0179	
	EXF 3.4. Max interaction with local population	Number of contact with local population	40	0.0124	
	EXF 3.5. Min attack on population	Number of attacks	57	0.0176	
	EXF 3.6. Min interaction with Govt Forces	Number of engagements with GOO	46	0.0142	
	EXF 3.7. Min casualties	Number of casualites	48	0.0149	
		TOTAL=	3232	1.0000	

F. SUMMARY

This chapter presented a proof of concept of the application of ICoMM by applying SE and SA processes to build a conceptual model of a HA/DR scenario. The incorporation of SMEs values and improved structure demonstrated that ICoMM can

facilitate face and traces validation techniques. It also identified methods for supporting the operational validation of a NOS by model exploration. The inclusion of SE methods in the MDP facilitated the identification of requirements, functional, and physical analysis. The analysis was conducted simultaneously for the system and the external system to demonstrate potential interaction between the two systems. The operational behaviors of the interactions are not directly observable. It is important to note that the functions of both systems affect each other in some way and the SMEs values of these functions must be documented during the building of the CoM. Therefore, it is important that a clearly traceable CoM is created prior to the execution of a simulation to minimize the uncertainty produced by the interaction of the two systems. ICoMM ensures that this information is available during the model exploration of a NOS.

V. CONCLUSION

A. SUMMARY

This research demonstrated the importance of an improved structure of the CoM for validation to gain greater trust by the DMs. A secondary result was gained by a greater understanding of the application of SE and SA processes to improve the structure of CoMs. ICoMM addresses the difficulty of operationally validating systems classified as non-observable that can be improved by designing the CoM early in the MPD with facilitated early SME involvement and a structure that logically connects the measurements to the fundamental objective.

The most recent research into this domain lacked structure to demonstrate clear traceability from the measures of performance and effectiveness to the fundamental objective. This research demonstrated that the application of SE processes to decompose systems and build models of the systems by applying SA techniques improves the traceability of the model. Traceability of the model is critical in supporting validation. Face validation techniques are normally applied when validating a NOS, as actual data may not exist to apply mathematical or simulation solutions. ICoMM demonstrated that the operational validation of models of a NOS could be improved with greater involvement of stakeholders by soliciting their values. Ultimately, the stakeholders validate the models of systems. The DOD defines validation as the following:

> The process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world from the perspective of the intended use(s). (Department of Defense 2009, 9)

Scenarios of potential future conflicts had to be created to gain an understanding of the unknown environment. This research chose to continue to model the HA/DR scenario of EW10 previously studied by NPS SE students and Georgia Tech to apply ICoMM for comparison. The scenario demonstrated that the non-observable aspect of the system was the interaction with the external system. Specification of the system was well known. However, the effects of the systems functions interacting with the external system

were not known and non-observable. Thus, operational validation of the system was not feasible and the only method to support operational validation was through model exploration of the CoM.

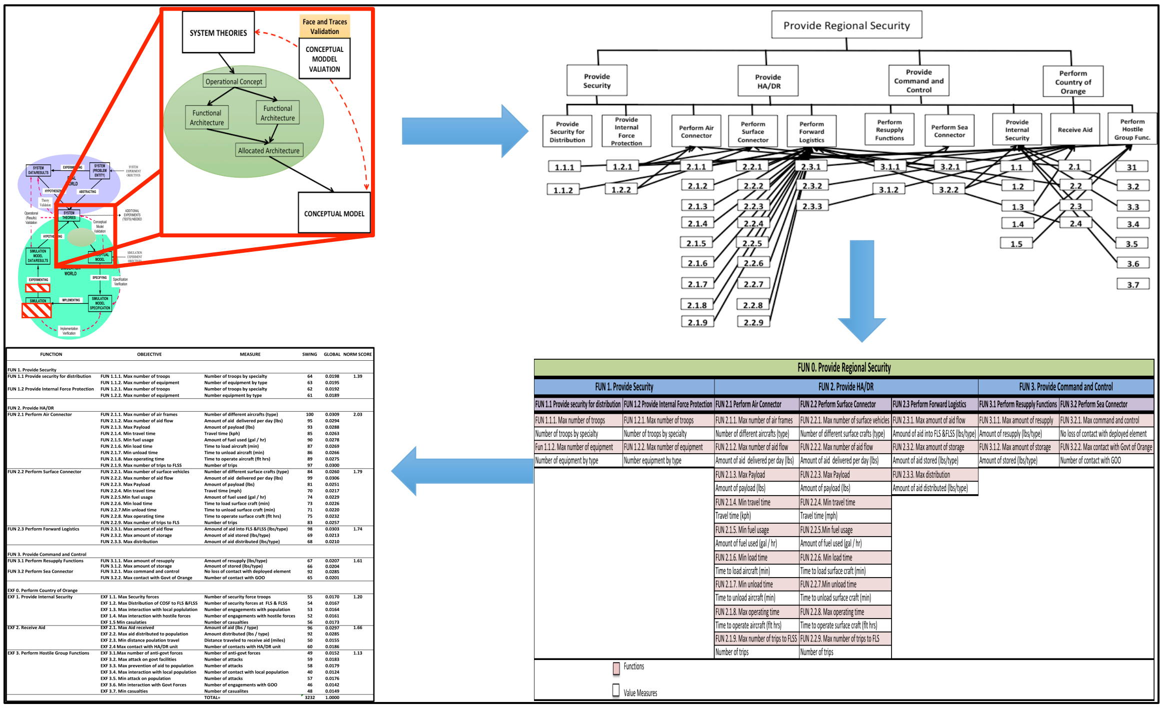
B. CONCLUSIONS

This research clearly demonstrated the utility of ICoMM in building well-structured CoMs by using SE and SA processes. Face and traces validation methods used for conceptual models are also improved using the SE and SA processes using ICoMM. This demonstration can be applied to future military operational assessments process. The methodology supports the following characteristics:

- Traceability—provides the stakeholders the ability to trace from MOPs and measures of effectiveness (MOEs) to fundamental objectives.
- Validation—supports face validation techniques traditionally used models and simulations of military operation by involving stakeholders early in the architecting process.
- Iterative—provides a method that can be repeated for different operational situations.

Figure 64 presents an overview of the dissertation of applying ICoMM to model development. Starting from the top-left corner, this research integrated SE and SA processes into Sargent’s (2001) Evolved MDP. The SE and SA processes decomposed the system to begin building the CoM in the top-right corner. The bottom-right corner shows a refined structure of the CoM that identifies the measurements and the supported objectives. Finally, the bottom-left corner shows the table of functions with SME inputs to provide quantifiable measurements to the NOS.

Figure 64. Dissertation Overview



Several things were revealed as a result of this research. There are many MDPs, but this research has not found one that demonstrates clearly how to transfer the systems definition to the development of the CoM. Many mention systems definition as a part of a MDP, but do not clearly outline the methodology. It is understood that most models built are of systems. Therefore, an understanding of SE processes if vital to building a model that represents the system.

The next revelation was that SMEs must be actively involved in building the model. The SMEs evaluate the model for correctness in representing the system in as real world environment and present their findings to DMs, which influences their decisions.

C. FUTURE WORK

This research was a continuation of a recent study of the modeling of NOSs for simulation. There remain a large number of potential extensions of this work. SE methodology was used in this research to decompose the system and to build an architecture that would improve the model of a NOS and the traceability for validation of

the model. The logical following step would be to find a simulation model that would use the steps outlined in this research to model the system and allow traceability from the measurements to the fundamental objectives. There has been research in conceptual models for discrete event simulations (DES). ICoMM may potentially be applied to build the initial state of the system for DES.

Another extension of this research would be to develop a system of systems (SOS). This research considers the interaction of the system and an external system but not the subsystems. SOS has five characteristics: operational independence, managerial independence, geographically distributed, emergent behavior, and evolutionary development (Rainey and Tolk 2014). These characteristics were not considered in this research. There would definitely be new challenges to trying to observe different systems performing with the five characteristics. The appearance of emergent behavior within the SOS and accounting for the unobservable behavior with the interaction of the external system would be very difficult.

Finally, applying this method in a real world environment would be the most desirable. This research was conducted with the military planners and assessment officers in mind. Any application that has the potential to assist these staff officers in conducting their daily business would be greatly beneficial to the U.S. military.

APPENDIX A. VITECH CORE OUTPUTS

OUTPUT PART 1 – Functions List

EXF.0 Perform Country of Orange Functions
EXF.1 Provides Internal Security (GOO)
EXF.2 Receive Aid
EXF.3 Perform Hostile Group Functions
FUN.0 Provide Regional Stability
FUN.1 Provide Security
FUN.1.1 Provide Security for distribution of Aid
FUN.1.2 Provide Internal Force Protection
FUN.2 Provide HA/DR
FUN.2.1 Perform Air Connector
FUN.2.2 Perform Surface Connector
FUN.2.3 Perform Forward Logistics
FUN.3 Provide Command and Control
FUN.3.1 Performs Resupply functions (Sea Base)
FUN.3.2 Perform Sea Connector
FUN.4 Provide Infrastructure Repair

Part II - Behavior Model

EXF.0 Perform Country of Orange Functions

Allocated To:
EXS.1 Government of Orange

Table 1 EXF.0 Perform Country of Orange Functions Interfacing Items

Interfacing Items	Source / Destination
Disaster Relief Conducted	Input To: EXF.0 Perform Country of Orange Functions Output From: FUN.2 Provide HA/DR
Secure Area	Input To: EXF.0 Perform Country of Orange Functions Output From: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid
State of the Country	Input To: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security

Table 1 EXF.0 Perform Country of Orange Functions Interfacing Items

Interfacing Items	Source / Destination
	FUN.2 Provide HA/DR FUN.3 Provide Command and Control Output From: EXF.0 Perform Country of Orange Functions

Table 1 EXF.0 Perform Country of Orange Functions Interfacing Items

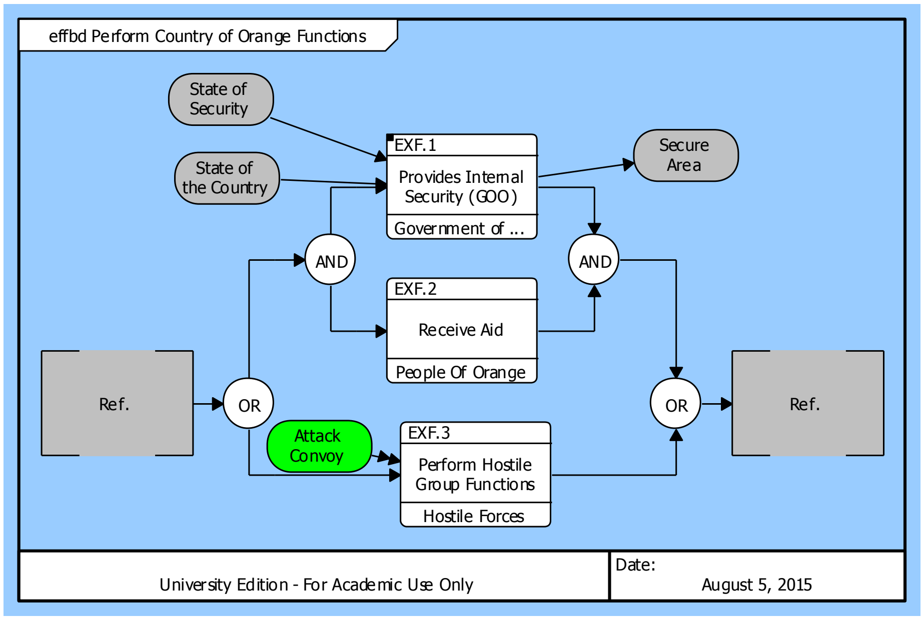


Figure 1 Perform Country of Orange Functions (Enhanced FFBD)

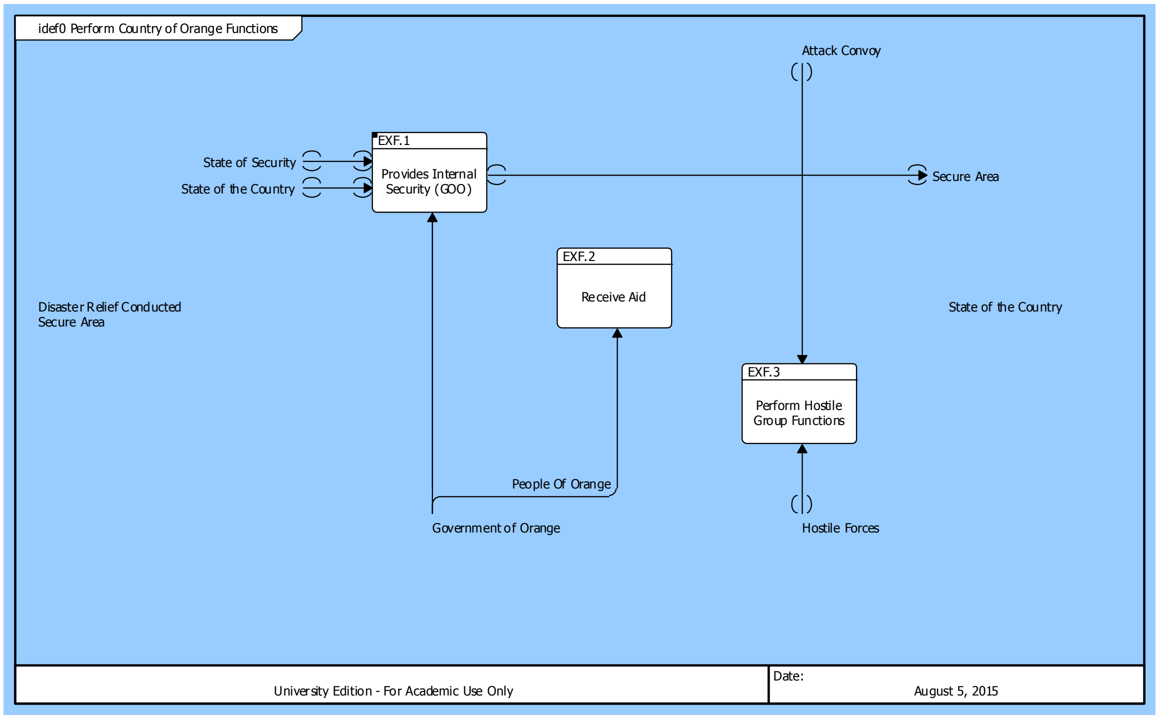


Figure 2 Perform Country of Orange Functions (IDEF0 Diagram)

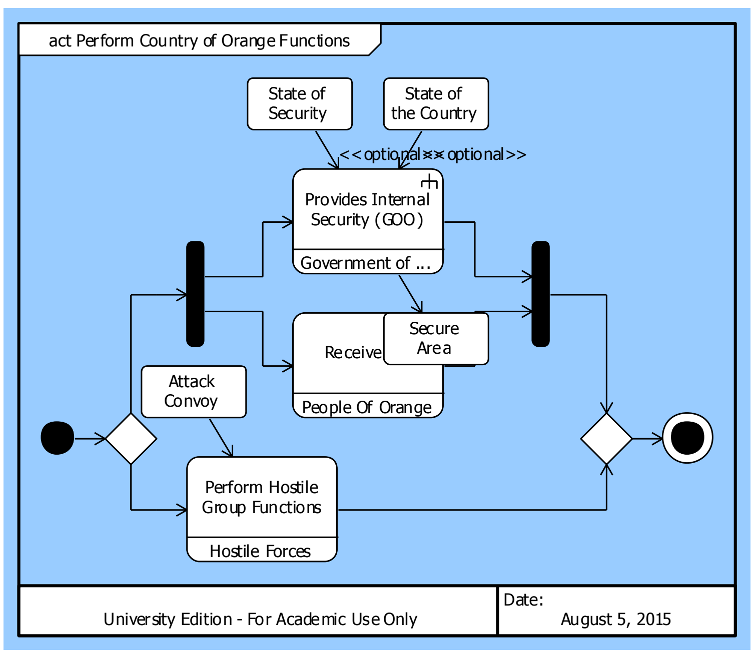


Figure 3 Perform Country of Orange Functions (Activity Diagram)

EXF.1 Provides Internal Security (GOO)

Allocated To:

EXS.1 Government of Orange

Table 2 EXF.1 Provides Internal Security (GOO) Interfacing Items

Interfacing Items	Source / Destination
Secure Area	Input To: EXF.0 Perform Country of Orange Functions Output From: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid
State of Security	Input To: EXF.1 Provides Internal Security (GOO) FUN.3 Provide Command and Control Output From: FUN.1 Provide Security
State of the Country	Input To: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.2 Provide HA/DR FUN.3 Provide Command and Control Output From: EXF.0 Perform Country of Orange Functions

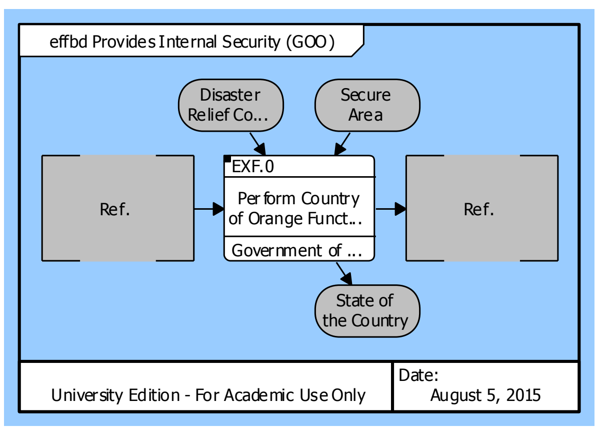


Figure 4 Provides Internal Security (GOO) (Enhanced FFBD)

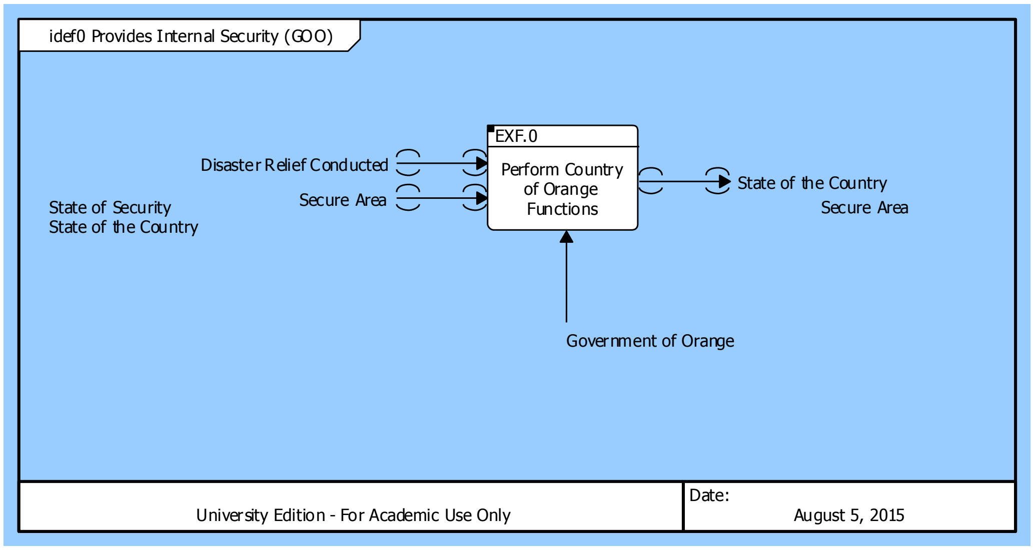


Figure 5 Provides Internal Security (GOO) (IDEF0 Diagram)

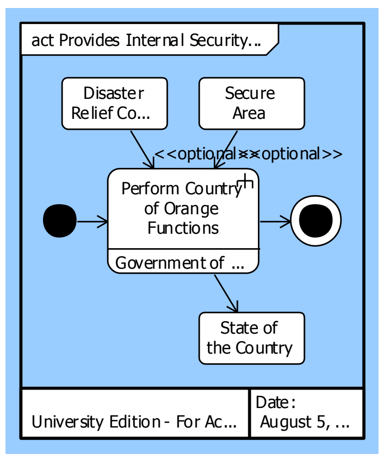


Figure 6 Provides Internal Security (GOO) (Activity Diagram)

EXF.2 Receive Aid

Allocated To:
EXS.1.2 People Of Orange

EXF.3 Perform Hostile Group Functions

Allocated To:
EXS.2 Hostile Forces

Table 3 EXF.3 Perform Hostile Group Functions Interfacing Items

Interfacing Items	Source / Destination
Attack Convoy	Triggers Function(s): EXF.3 Perform Hostile Group Functions

FUN.0 Provide Regional Stability

Allocated To:
   0 HA/FA Mission

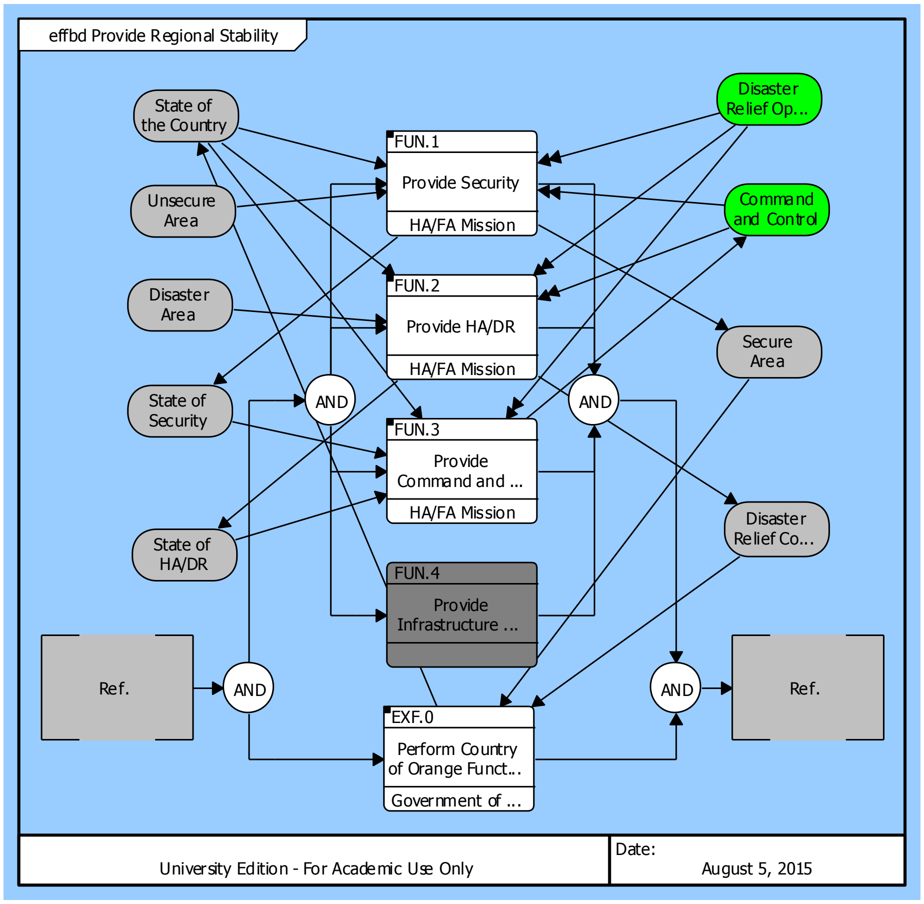


Figure 7 Provide Regional Stability (Enhanced FFBD)

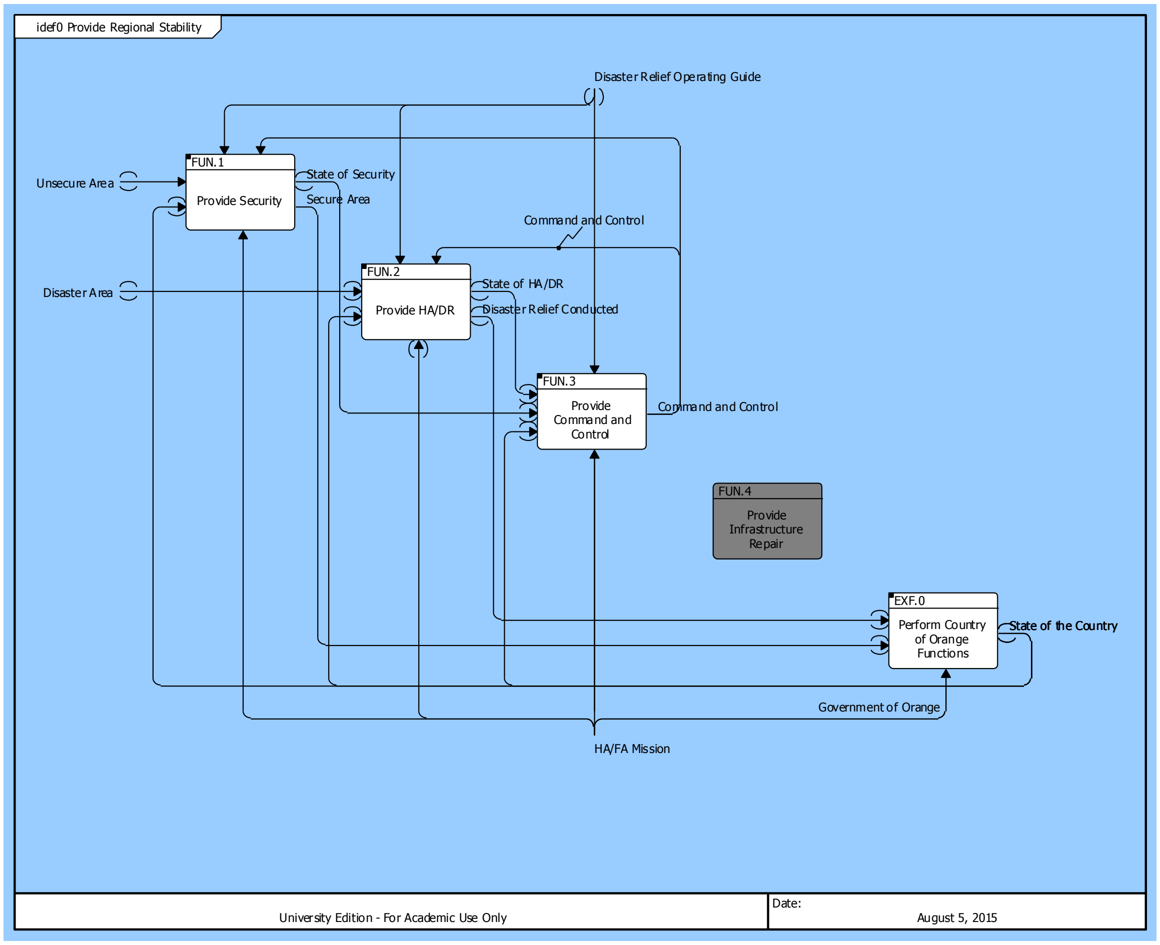


Figure 8 Provide Regional Stability (IDEF0 Diagram)

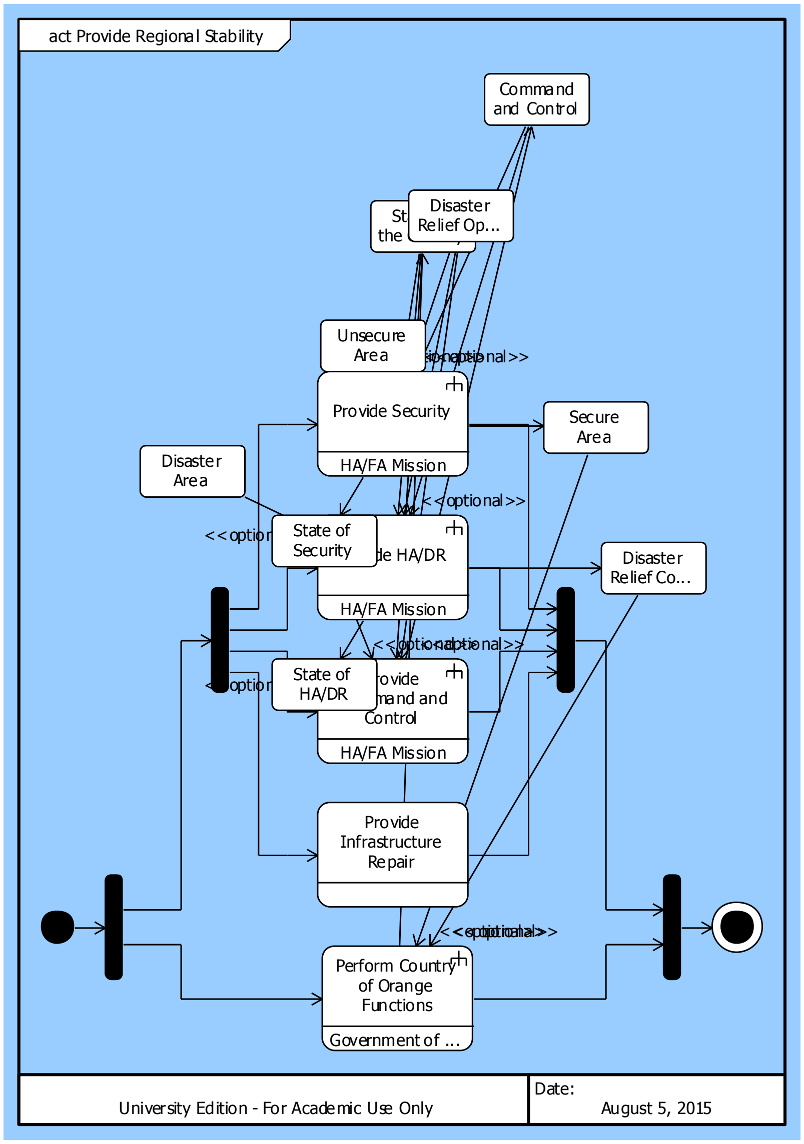


Figure 9 Provide Regional Stability (Activity Diagram)

FUN.1 Provide Security

Allocated To:
  0 HA/FA Mission

Specified By Requirements:
  REQ.2.1 Provide Security (Sea)
  REQ.3.1 Provide Security (Air)
  REQ.4.2 Provide Security (Surface)

Table 4 FUN.1 Provide Security Interfacing Items

Interfacing Items	Source / Destination
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Secure Area	Input To: EXF.0 Perform Country of Orange Functions Output From: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid
State of Security	Input To: EXF.1 Provides Internal Security (GOO) FUN.3 Provide Command and Control Output From: FUN.1 Provide Security
State of the Country	Input To: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.2 Provide HA/DR FUN.3 Provide Command and Control Output From: EXF.0 Perform Country of Orange Functions
Unsecure Area	Input To: FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection

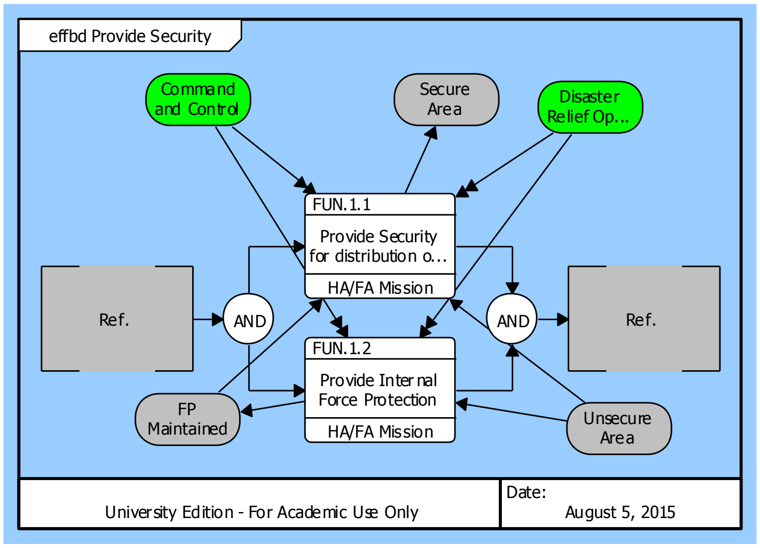


Figure 10 Provide Security (Enhanced FFBD)

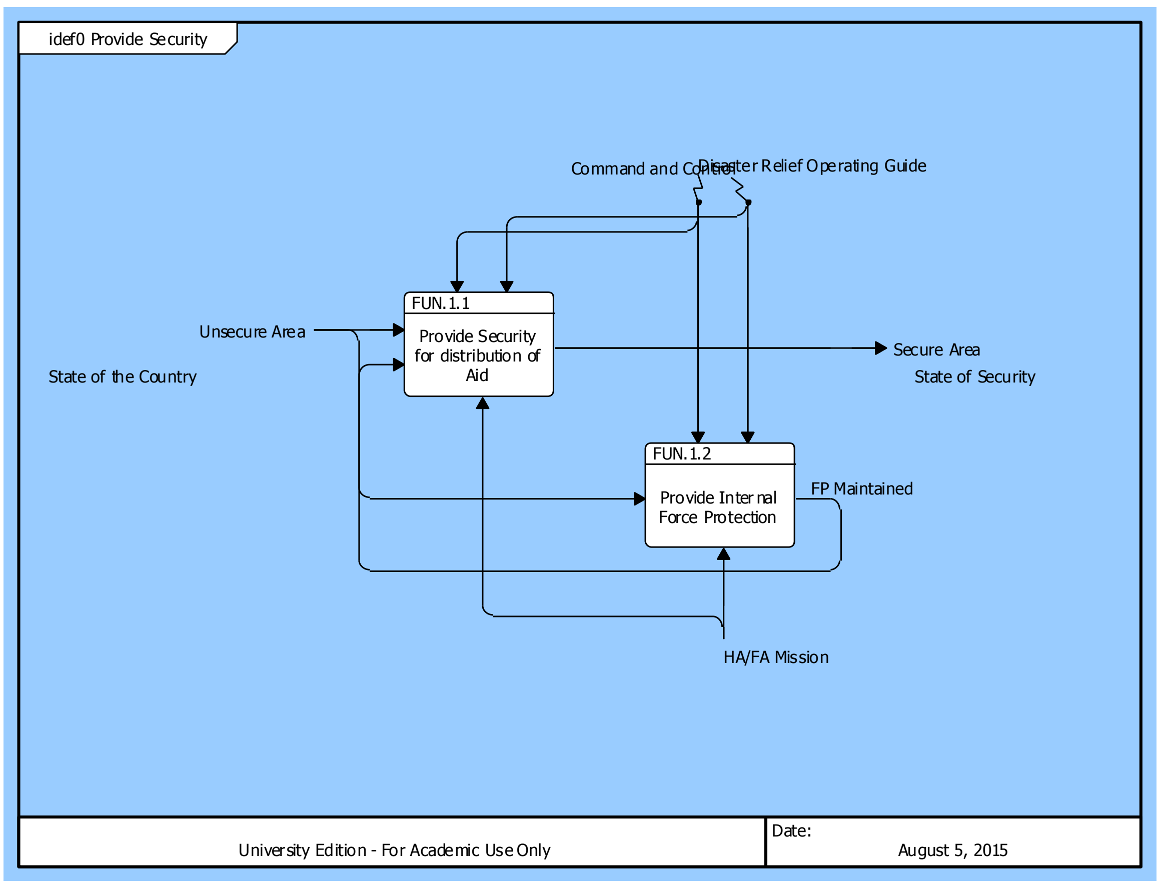


Figure 11 Provide Security (IDEF0 Diagram)

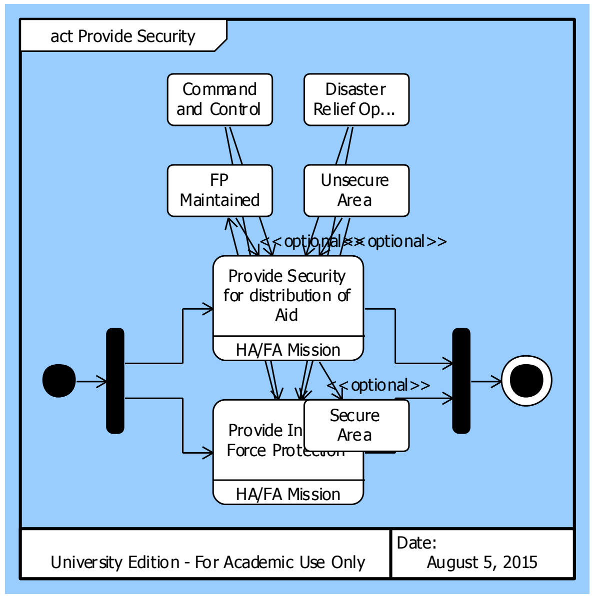


Figure 12 Provide Security (Activity Diagram)

FUN.1.1 Provide Security for distribution of Aid

Allocated To:
0 HA/FA Mission

Table 5 FUN.1.1 Provide Security for distribution of Aid Interfacing Items

Interfacing Items	Source / Destination
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector

Table 5 FUN.1.1 Provide Security for distribution of Aid Interfacing Items

Interfacing Items	Source / Destination
FP Maintained	Input To: FUN.1.1 Provide Security for distribution of Aid Output From: FUN.1.2 Provide Internal Force Protection
Secure Area	Input To: EXF.0 Perform Country of Orange Functions Output From: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid
Unsecure Area	Input To: FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection

Table 6 FUN.1.2 Provide Internal Force Protection Interfacing Items

Interfacing Items	Source / Destination
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
FP Maintained	Input To: FUN.1.1 Provide Security for distribution of Aid Output From: FUN.1.2 Provide Internal Force Protection
Unsecure Area	Input To:

Table 6 FUN.1.2 Provide Internal Force Protection Interfacing Items

Interfacing Items	Source / Destination
	FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection

FUN.2 Provide HA/DR

Allocated To:
0 HA/FA Mission

Table 7 FUN.2 Provide HA/DR Interfacing Items

Interfacing Items	Source / Destination
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Area	Input To: FUN.2 Provide HA/DR
Disaster Relief Conducted	Input To: EXF.0 Perform Country of Orange Functions Output From: FUN.2 Provide HA/DR
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
State of HA/DR	Input To: FUN.3 Provide Command and Control Output From: FUN.2 Provide HA/DR
State of the Country	Input To: EXF.1 Provides Internal Security (GOO)

Table 7 FUN.2 Provide HA/DR Interfacing Items

Interfacing Items	Source / Destination
	FUN.1 Provide Security FUN.2 Provide HA/DR FUN.3 Provide Command and Control Output From: EXF.0 Perform Country of Orange Functions

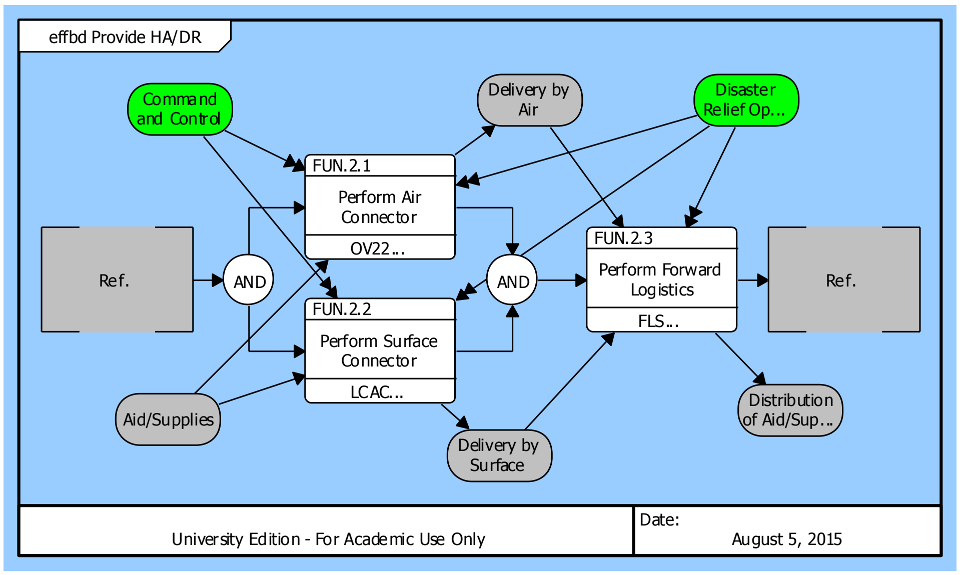


Figure 13 Provide HA/DR (Enhanced FFBD)

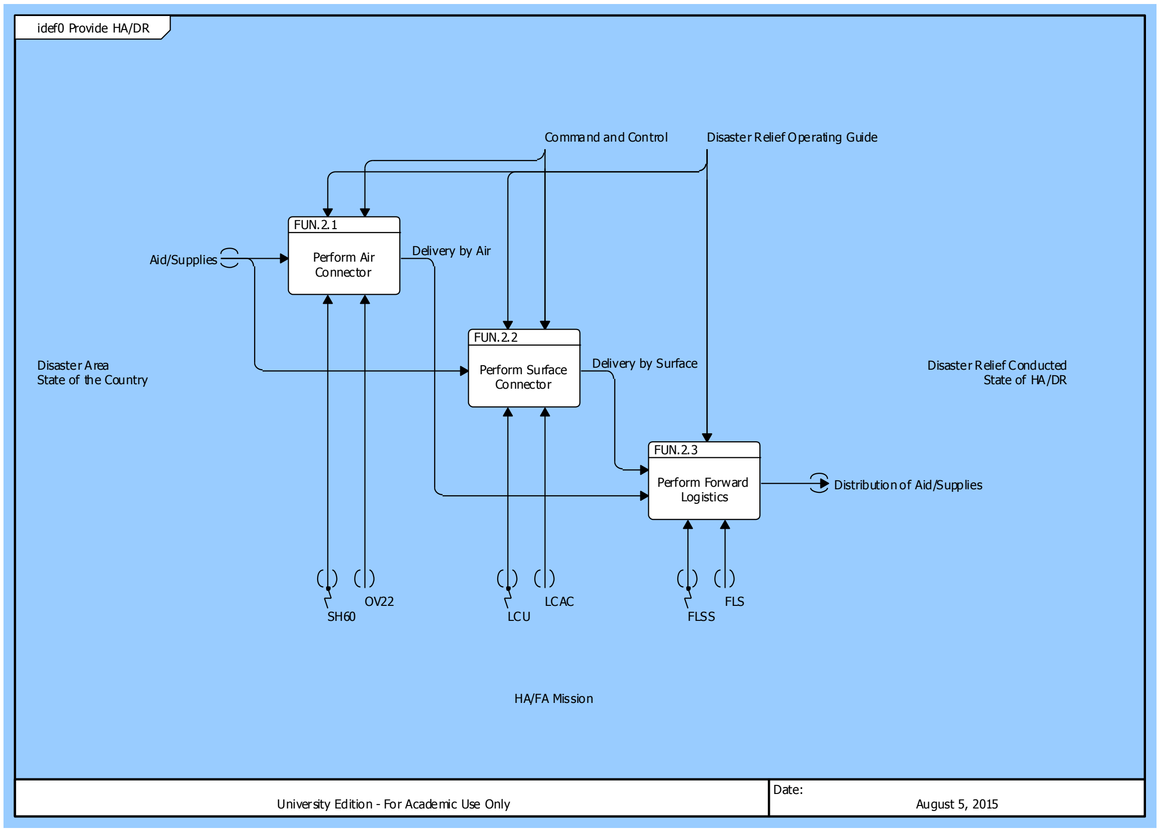


Figure 14 Provide HA/DR (IDEF0 Diagram)

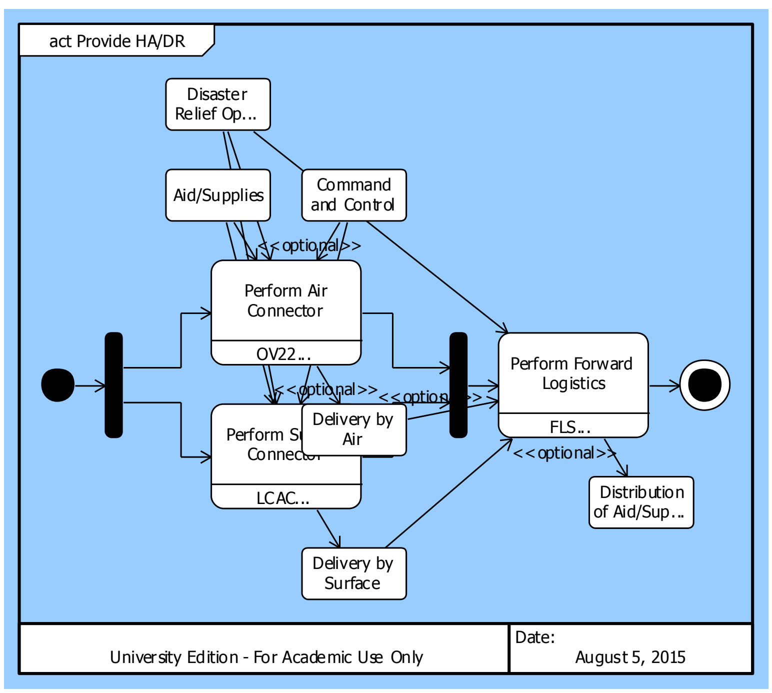


Figure 15 Provide HA/DR (Activity Diagram)

FUN.2.1 Perform Air Connector

Allocated To:
COMP.2.2 SH60
COMP.2.3 OV22

Table 8 FUN.2.1 Perform Air Connector Interfacing Items

Interfacing Items	Source / Destination
Aid/Supplies	Input To: FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Delivery by Air	Input To: FUN.2.3 Perform Forward Logistics Output From: FUN.2.1 Perform Air Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector

FUN.2.2 Perform Surface Connector

Allocated To:

COMP.3.1 LCAC
COMP.3.2 LCU

Table 9 FUN.2.2 Perform Surface Connector Interfacing Items

Interfacing Items	Source / Destination
Aid/Supplies	Input To: FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Delivery by Surface	Input To: FUN.2.3 Perform Forward Logistics Output From: FUN.2.2 Perform Surface Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector

FUN.2.3 Perform Forward Logistics

Allocated To:
COMP.4.1 FLS
COMP.4.2 FLSS

Table 10 FUN.2.3 Perform Forward Logistics Interfacing Items

Interfacing Items	Source / Destination
Delivery by Air	Input To: FUN.2.3 Perform Forward Logistics Output From: FUN.2.1 Perform Air Connector
Delivery by Surface	Input To: FUN.2.3 Perform Forward Logistics Output From: FUN.2.2 Perform Surface Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Distribution of Aid/Supplies	Output From: FUN.2.3 Perform Forward Logistics

FUN.3 Provide Command and Control

Allocated To:
0 HA/FA Mission

Table 11 FUN.3 Provide Command and Control Interfacing Items

Interfacing Items	Source / Destination
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security

Table 11 FUN.3 Provide Command and Control Interfacing Items

Interfacing Items	Source / Destination
	FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
State of HA/DR	Input To: FUN.3 Provide Command and Control Output From: FUN.2 Provide HA/DR
State of Security	Input To: EXF.1 Provides Internal Security (GOO) FUN.3 Provide Command and Control Output From: FUN.1 Provide Security
State of the Country	Input To: EXF.1 Provides Internal Security (GOO) FUN.1 Provide Security FUN.2 Provide HA/DR FUN.3 Provide Command and Control Output From: EXF.0 Perform Country of Orange Functions

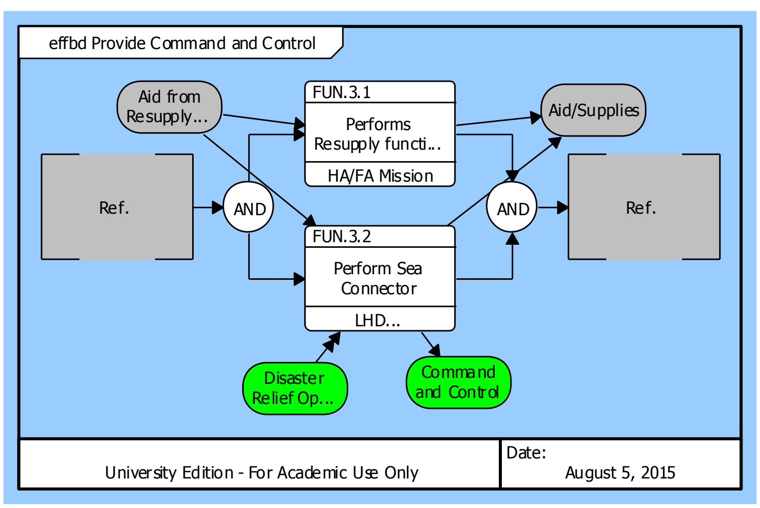


Figure 16 Provide Command and Control (Enhanced FFBD)

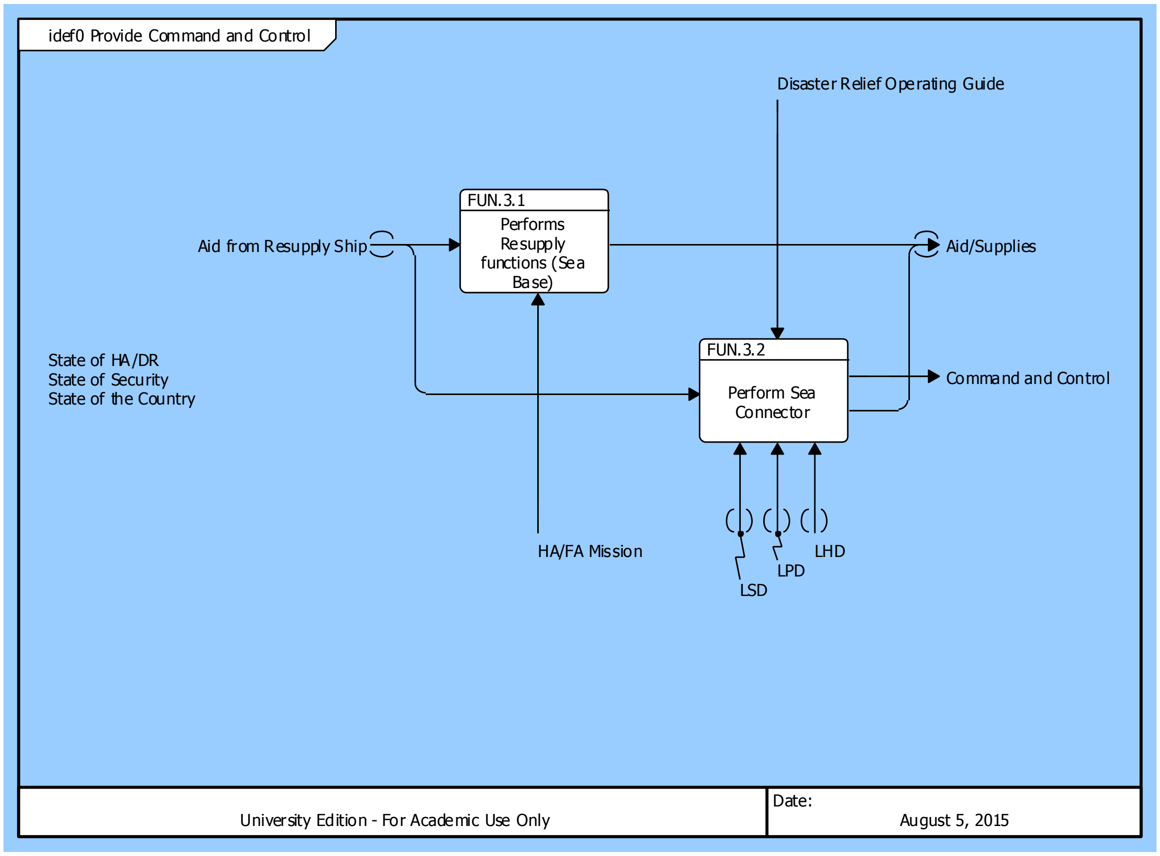


Figure 17 Provide Command and Control (IDEF0 Diagram)

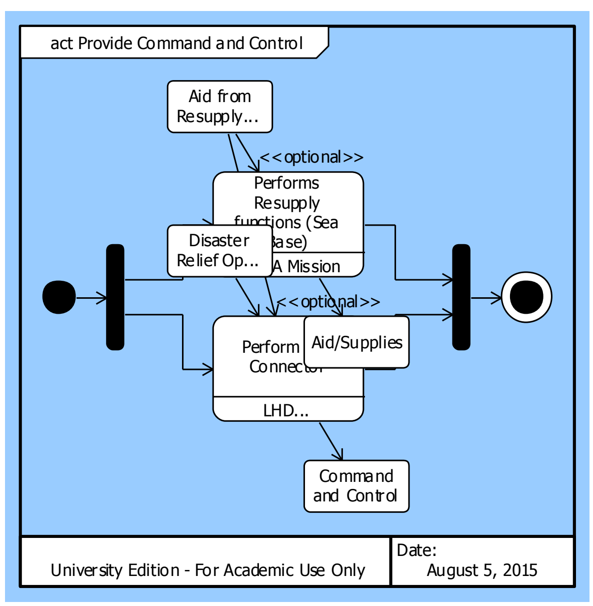


Figure 18 Provide Command and Control (Activity Diagram)

FUN.3.1 Performs Resupply functions (Sea Base)

Allocated To:
0 HA/FA Mission

Table 12 FUN.3.1 Performs Resupply functions (Sea Base) Interfacing Items

Interfacing Items	Source / Destination
Aid from Resupply Ship	Input To: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector
Aid/Supplies	Input To: FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector

FUN.3.2 Perform Sea Connector

Allocated To:
COMP.1.2 LHD
COMP.1.3 LPD
COMP.1.4 LSD

Table 13 FUN.3.2 Perform Sea Connector Interfacing Items

Interfacing Items	Source / Destination
Aid from Resupply Ship	Input To: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector
Aid/Supplies	Input To: FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector Output From: FUN.3.1 Performs Resupply functions (Sea Base) FUN.3.2 Perform Sea Connector
Command and Control	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector

Table 13 FUN.3.2 Perform Sea Connector Interfacing Items

Interfacing Items	Source / Destination
	Output From: FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector
Disaster Relief Operating Guide	Triggers Function(s): FUN.1 Provide Security FUN.1.1 Provide Security for distribution of Aid FUN.1.2 Provide Internal Force Protection FUN.2 Provide HA/DR FUN.2.1 Perform Air Connector FUN.2.2 Perform Surface Connector FUN.2.3 Perform Forward Logistics FUN.3 Provide Command and Control FUN.3.2 Perform Sea Connector

{tc "6 Components Part I – Components List

0 HA/FA Mission
COMP.1 Sea Base Connector
COMP.1.2 LHD
COMP.1.3 LPD
COMP.1.4 LSD
COMP.2 Air Connector
COMP.2.1 MH53
COMP.2.2 SH60
COMP.2.3 OV22
COMP.3 Surface Connector
COMP.3.1 LCAC
COMP.3.2 LCU
COMP.4 Logistcal Sites
COMP.4.1 FLS
COMP.4.2 FLSS
EXS.1 Government of Orange
EXS.1.2 People Of Orange
EXS.2 Hostile Forces

Part II - Component Definitions

0 HA/FA Mission

Type: System of Systems

Built From Lower-Level Component(s):
COMP.1 Sea Base Connector
COMP.4 Logistcal Sites
EXS.1 Government of Orange
EXS.2 Hostile Forces

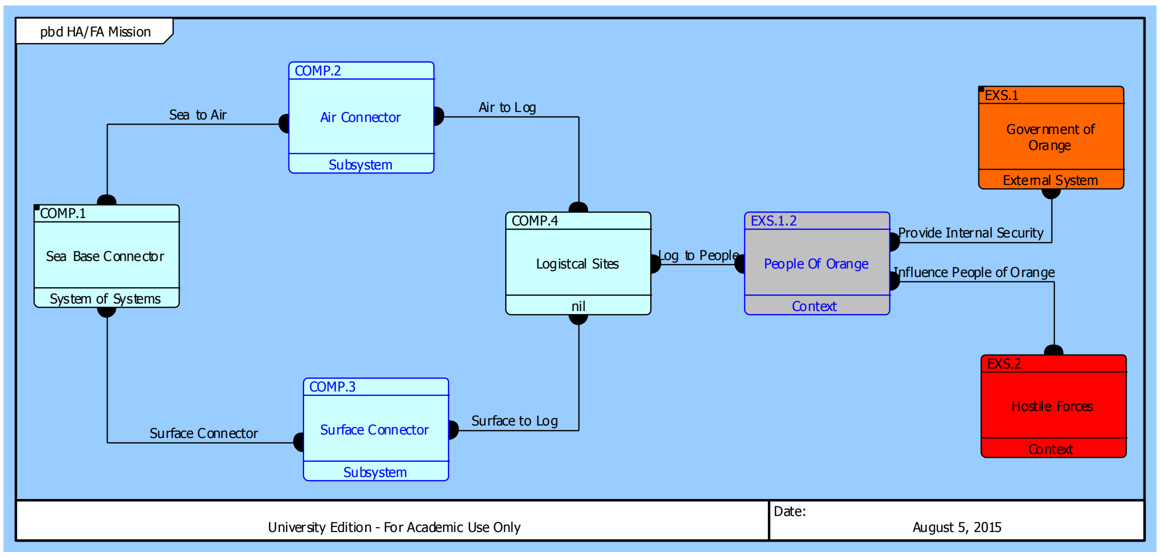


Figure 19 HA/FA Mission (Physical Block Diagram)

Performs Function(s):
FUN.0 Provide Regional Stability
FUN.1 Provide Security
FUN.1.1 Provide Security for distribution of Aid
FUN.1.2 Provide Internal Force Protection
FUN.2 Provide HA/DR
FUN.3 Provide Command and Control
FUN.3.1 Performs Resupply functions (Sea Base)

COMP.1 Sea Base Connector

Description:
The system context identifies the physical context (the environment and external systems your system interacts with) enabling you to specify the system boundary.

Type: System of Systems

Built In Higher-Level Component(s):
0 HA/FA Mission

Built From Lower-Level Component(s):
COMP.2 Air Connector

COMP.3 Surface Connector

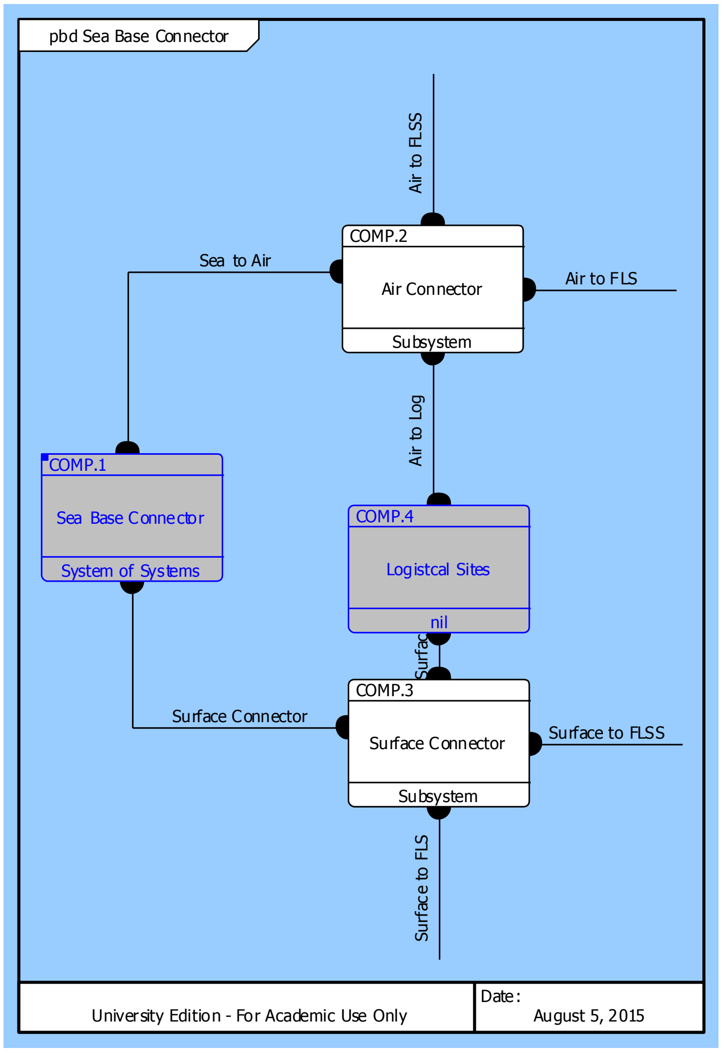


Figure 20 Sea Base Connector (Physical Block Diagram)

Connected to Physical Link(s):
    Sea to Air
    Surface Connector

COMP.1.2 LHD

Type: System

Performs Function(s):
    FUN.3.2 Perform Sea Connector

COMP.1.3 LPD

Performs Function(s):
FUN.3.2 Perform Sea Connector

COMP.1.4 LSD

Performs Function(s):
FUN.3.2 Perform Sea Connector

COMP.2 Air Connector

Type: Subsystem

Built In Higher-Level Component(s):
COMP.1 Sea Base Connector

Connected to Physical Link(s):
Air to FLS
Air to FLSS
Air to Log
Sea to Air

COMP.2.1 MH53

COMP.2.2 SH60

Performs Function(s):
FUN.2.1 Perform Air Connector

COMP.2.3 OV22

Performs Function(s):
FUN.2.1 Perform Air Connector

COMP.3 Surface Connector

Type: Subsystem

Built In Higher-Level Component(s):
COMP.1 Sea Base Connector

Connected to Physical Link(s):
Surface Connector
Surface to FLS
Surface to FLSS
Surface to Log

COMP.3.1 LCAC

Performs Function(s):
FUN.2.2 Perform Surface Connector

COMP.3.2 LCU

Performs Function(s):
FUN.2.2 Perform Surface Connector

COMP.4 Logistcal Sites

Built In Higher-Level Component(s):
0 HA/FA Mission

Connected to Physical Link(s):
Air to Log
Log to People
Surface to Log

COMP.4.1 FLS

Performs Function(s):
FUN.2.3 Perform Forward Logistics

COMP.4.2 FLSS

Performs Function(s):
FUN.2.3 Perform Forward Logistics

EXS.1 Government of Orange

Type: External System

Built In Higher-Level Component(s):
0 HA/FA Mission

Built From Lower-Level Component(s):
EXS.1.2 People Of Orange

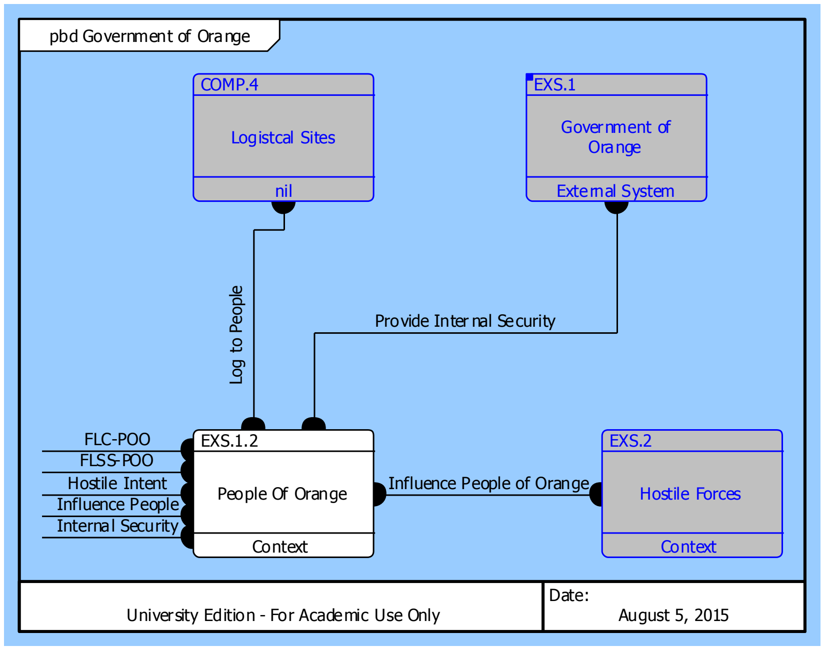


Figure 21 Government of Orange (Physical Block Diagram)

Connected to Physical Link(s):
  Provide Internal Security

Performs Function(s):
  EXF.0 Perform Country of Orange Functions
EXF.1 Provides Internal Security (GOO)

EXS.1.2 People Of Orange

Type: Context

Built In Higher-Level Component(s):
  EXS.1 Government of Orange

Connected to Physical Link(s):
  FLC-POO
  FLSS-POO
  Hostile Intent
  Influence People
  Influence People of Orange
  Internal Security
  Log to People
  Provide Internal Security

Performs Function(s):
  EXF.2 Receive Aid

EXS.2 Hostile Forces

Type: Context

Built In Higher-Level Component(s):
0 HA/FA Mission

Connected to Physical Link(s):
Influence People of Orange

Performs Function(s):
EXF.3 Perform Hostile Group Functions

APPENDIX B. VEHICLE PLATFORM SPECIFICATIONS

The following table is the list of capabilities for each of the platforms used in the HA/DR mission.

	Sea Base			Sea Connectors		Air Connectors		
	LHD	LPD	LSD	LCAC	LCU	MH-53	OV-22	SH-60
Velocity (kts) - Seabase Ops	7	7	7	40	8	150	215	160
Payload (U.S. tons)	2711.69	2535.32	1234.59	75	170	18	17.5	3
Fuel Capacity	585000	314160	50000	5000	N/A	2277	1448	590
Refuel Initiation Threshold (%)	30	30	30	30	30	30	30	30
Refuel Completion Threshold (%)	95	95	95	100	100	100	100	100
Refuel Rate (at sea - Gal/hr)	252000	252000	252000	60000	N/A	60000	60000	60000
Replenishment Initiation Threshold (%)	0	0	0	0	0	0	0	0
Replenishment Completion Threshold (%)	100	100	100	100	100	100	100	100
Replenishment Rate (at sea - U.S. Tons/hr)	210	210	210					
Load Time (Hr)				2	4.5	0.01666667	0.03333333	0.01666667
Unload Time (Hr)				2	4.5	0.01666667	0.03333333	0.01666667
Range before Refuel (Nmi)				200	1200	700	950	450
Fuel Consumption time (Hr)				5	150	4.67	4.4	2.8
Operating Time Limit (Hr/Day)				16	16	8	8	8

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